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PROBLEMS IN ALTERNATING CURRENT MACHINERY

BY

WALDO V. LYON
Professor of Electrical Machinery,
Massachusetts Institute of Technology

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PREFACE TO THE SECOND EDITION

In this second edition practically all of the problems in the first edition concerning alternating current machines have been retained. To these have been added an equal number which relate to other phases of the theory. Through the courtesy of two of the large manufacturing companies the author has been able to give data on about fifty additional machines ranging in size from one of a few kilowatts to a synchronous condenser of 40,000 kv.a. capacity. It will be observed that many of the new problems have been arranged so that they are susceptible to as many as forty or fifty variations. This was done to increase the useful life of the book. The answers to approximately 200 representative problems are now available.

It is now 15 years since work on the original collection of problems was begun. During this time the author has been closely associated with Professor Ralph R. Lawrence in teaching the theory of alternating currents and machinery, and many of the problems in the present collection were suggested by him.

WALDO V. LYON.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY,
September, 1928.

PREFACE TO THE FIRST EDITION

These problems chiefly concern the theory of the operation of alternating current machinery, and are such as we give to the fourth year students in electrical engineering in this subject.

In each chapter the problems of a similar nature are grouped together, and those of each group are then arranged in the approximate order of their difficulty. The groups in each chapter follow each other in as logical an order as possible, both from point of difficulty and the presentation of the subject.

In order that this collection of problems may be useful among different classes of students a large variety has been included, ranging from the very simple to those of considerable difficulty. Wherever it is essential the data have been taken from actual apparatus. This was possible through the courtesy of two of the large manufacturing companies. In some of the problems so few data are given that approximate methods of solution must be used, but care has been taken to so state them that the errors thus introduced need not be large. This lack of data is frequently met in practice.

It has been thought best not to give introductory paragraphs for each chapter as was done in the preceding volume of problems inasmuch as they would have to be of considerable length to be of much value.

WALDO V. LYON.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY,
December, 1913.

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INTRODUCTION

The great importance of problem work in the training of students of engineering is now generally recognized. No other work so efficiently develops analytical power and clear, logical thinking, so necessary to success in the engineering profession. Yet notwithstanding the importance of problem work in general, the first consistently developed book of electrical engineering problems was that prepared by Mr. Lyon in 1908, its wide use being conclusive evidence of the needs that were felt among both teachers and students for such a work, and of the appreciation of the importance of the training which it exemplifies.

It requires a special gift to originate and develop problems which shall give sound training in the fundamentals of engineering and whose solution shall not only interest the student, but develop his intellectual power as well. In general the problems must be closely related to engineering practice, graded as to difficulty, and must carefully avoid being mere mathematical puzzles. Mr. Lyon, as his earlier book also shows, has a most unusual ability in the preparation of problems for the electrical engineering field.

The present collection of problems relating to electrical machinery, more particularly in the field of alternating current engineering, has been prepared with the same point of view as was Mr. Lyon's earlier work, and should likewise prove most useful to both instructor and student.

H. E. Clifford.

Harvard University,
December, 1913.

PROBLEMS IN ALTERNATING CURRENT MACHINERY

CHAPTER I

TRANSFORMERS

1. The iron loss in a reactor is 240 watts of which 48 watts is due to eddy currents. If the amount of iron in the magnetic circuit were doubled by doubling the cross-section of the core, what would be the iron loss at the same applied potential and frequency? Neglect the resistance.

2. The iron loss in a reactor is 312 watts of which 86 watts is due to eddy currents. If a similar reactor were constructed in which laminations of twice the thickness were used, what would be the iron loss at the same applied potential and frequency? Neglect the resistance.

3. When 110 volts at 30 cycles is applied to a reactor, the iron loss is 276 watts of which 204 watts is due to hysteresis. If the applied potential and frequency are both doubled, what will be the iron loss? Neglect the resistance.

4. When 110 volts at 60 cycles is applied to a reactor, the iron loss is 248 watts of which 25 per cent is due to eddy currents. (*a*) What will be the iron loss when 220 volts at 60 cycles is applied to the reactor? (*b*) What will be the iron loss when 110 volts at 30 cycles is applied to the reactor? Neglect the resistance.

5. A reactor has two electric circuits having the same number of turns which may be connected in series or in parallel. When they are connected in series across 220-volt, 60-cycle mains, the iron loss is 326 watts, of which 89 watts is due to eddy currents. What will be the iron loss if the coils are connected in parallel across the same mains? Neglect the resistance.

6. With 425 volts at 25 cycles applied to the low-tension winding of a transformer, 2500 watts is supplied at no load. If

the frequency of this applied potential is increased to 40 cycles without changing its root-mean-square value, 2020 watts is supplied at no load. What is the division between the eddy-current and hysteresis losses at 25 cycles?

7. With 440 volts at 50 cycles applied to the low-tension winding of a transformer, 641 watts is supplied at no load. If the frequency and potential are each reduced 50 per cent, 278 watts is supplied at no load. What is the division between the eddy-current and hysteresis losses at 50 cycles?

8. With 440 volts at 60 cycles applied to the low-tension winding of a transformer, 371 watts is supplied at no load. If the potential is reduced 50 per cent without changing the frequency, 114 watts is supplied at no load. What is the division between the eddy-current and hysteresis losses at 440 volts?

9. At no load with 220 volts at 60 cycles impressed on a transformer, the ratio of eddy-current to hysteresis loss is 1:3. What is this ratio if 220 volts at 50 cycles is impressed on the transformer?

10. At no load with 220 volts at 60 cycles impressed on a transformer, the ratio of eddy-current to hysteresis loss is 1:3. What is this ratio if 110 volts at 60 cycles is impressed on the transformer?

11. From the iron-loss curves which are given at 25 cycles and at 60 cycles for sample A, B, C, or D, construct an iron-loss curve (*a*) at 30 cycles, (*b*) at 50 cycles.

12. From the iron-loss curves which are given at 25 cycles and at 60 cycles for sample A, B, C, or D, construct an iron-loss curve at 60 cycles for the same quality of material (*a*) in 16-mil sheets, (*b*) in 12-mil sheets.

13. From the iron-loss curves which are given at 25 cycles and at 60 cycles for sample A, B, C, or D, construct an iron-loss curve at 25 cycles for the same quality of material (*a*) in 16-mil sheets, (*b*) in 12-mil sheets.

14. From the iron-loss curves which are given for sample A, B, C, or D, determine the ratio of eddy-current to hysteresis loss at a density (*a*) of 10,000 gausses, (*b*) of 70 kilolines per square inch, (*c*) of 12,000 gausses, and a frequency (1) of 25 cycles, (2) of 60 cycles.

15.[1] What would have been the iron loss in transformer L, . . . P, . . . or U at the rated potential and frequency

[1] Assume that the original ratio of eddy-current to hysteresis loss is 1:3.

if the cross-section of the core had been (*a*) 5 per cent greater, (*b*) 5 per cent less?

16.[1] What would have been the iron loss in transformer L, . P, . . . or U at the rated potential and frequency if the number of turns in each of the windings had been (*a*) 5 per cent greater, (*b*) 5 per cent less?

17.[1] What will be the iron loss in transformer L, . . . P, . . . or U at the rated frequency if the applied potential is (*a*) increased 5 per cent, (*b*) reduced 5 per cent?

18.[1] What will be the iron loss in transformer L, . . . P, . . or U if the frequency of the applied potential alone is (*a*) increased 5 per cent, (*b*) reduced 5 per cent?

19.[1] What would have been the iron loss in transformer L, . . . P, . . . or U if the core had been constructed (*a*) of 16-mil iron instead of 14-mil iron, (*b*) of 12-mil iron instead of 14-mil iron?

20. If a simple-harmonic electromotive force of 2200 volts at 60 cycles is applied to the low-tension winding of a transformer, the core loss is 940 watts, 23 per cent of which is due to eddy currents. What will be the core loss if an e.m.f. of the same effective value and frequency but (*a*) with a form factor of 1.05[2] is impressed on the low-tension winding, (*b*) if an e.m.f. of the same effective value and frequency but with a form factor of 1.2[3] is applied to the low-tension winding?

21. A potential of the form $E_1 \sin \omega t + E_3 \sin 3\omega t$ is applied to a transformer. What is the greatest value of E_3/E_1 in order that the curve showing the relation between the flux density and the magnetizing force—*i.e.*, the hysteresis loop—shall have no interior loops?

22. A potential of the form $E_1 \sin \omega t - E_3 \sin 3\omega t$ is applied to a transformer. What is the greatest value of E_3/E_1 in order that the curve showing the relation between the flux density and the magnetizing force—*i.e.*, the hysteresis loop—shall have no interior loops?

23.[1] What is the iron loss of transformer L, . . . P, . . . or U when the applied potential has its rated value but is non-sinusoidal, having a wave form of $\sin \omega t + 0.1 \sin 3\omega t$?

[1] Assume that the original ratio of eddy-current to hysteresis loss is 1:3.

[2] Flat topped

[3] Peaked

24.[1] What is the iron loss of transformer L, . . . P, . . . or U when the applied potential has its rated value but is non-sinusoidal, having a wave form of $\sin \omega t - 0.1 \sin 3\omega t$?

25.[2] The magnetic core of transformer L, . . . P, . . . or U is built of steel of the quality of sample A, B, C, or D. What will be the iron loss at the rated frequency and potential if the wave form of the potential is $E \sin \omega t + 0.1\, E \sin 3\omega t$?

26.[2] The magnetic core of transformer L, . . . P, . . . or U is built of steel of the quality of sample A, B, C, or D. What will be the iron loss at the rated frequency and potential if the wave form of the potential is $E \sin \omega t - 0.1E \sin 3\omega t$?

27. The magnetic core of a transformer is built of steel which has, for a maximum flux density of 10,000 gausses, the hysteresis loop 1. The potential applied to this transformer is sinusoidal and of such value that the maximum flux density is 10,000 gausses. On the assumption that the effect of eddy currents may be neglected, construct a curve showing the wave form of the exciting current. Determine the ratio of the maximum to the root-mean-square value of this current.

28. The magnetic core of a transformer is built of steel which has, for a maximum flux density of 15,000 gausses, the hysteresis loop 2. The potential applied to this transformer is sinusoidal and of such value that the maximum flux density is 15,000 gausses. On the assumption that the effect of eddy currents may be neglected, construct a curve showing the wave form of the exciting current. Determine the ratio of the maximum to the r.m.s. value of this current.

29. The magnetic core of a transformer is built of steel which has, for a maximum flux density of 10,000 gausses, the hysteresis loop 1. The wave form of the potential applied to this transformer is $E \sin \omega t + 0.1E \sin 3\omega t$ and is of such value that the maximum flux density is 10,000 gausses. On the assumption that the effect of eddy currents may be neglected, construct a curve showing the wave form of the exciting current. Determine the ratio of the maximum to the r.m.s. value of this current.

30. The magnetic core of a transformer is built of steel which has, for a maximum flux density of 15,000 gausses, the hysteresis loop 2. The wave form of the potential applied to this transformer is $E \sin \omega t + 0.1E \sin 3\omega t$ and is of such value that the

[1] Assume that the original ratio of eddy-current to hysteresis loss is 1:3.

[2] Assume that the transformers are designed for a maximum flux density of 11 kilogausses.

maximum flux density is 15,000 gausses. On the assumption that the effect of eddy currents may be neglected, construct a curve showing the wave form of the exciting current. Determine the ratio of the maximum to the r.m.s. value of this current.

31. The magnetic core of a transformer is built of steel which has, for a maximum flux density of 10,000 gausses, the hysteresis loop 1. The wave form of the potential applied to this transformer is $E \sin \omega t - 0.1E \sin 3\omega t$ and is of such value that the maximum flux density is 10,000 gausses. On the assumption that the effect of eddy currents may be neglected, construct a curve showing the wave form of the exciting current. Determine the ratio of the maximum to the r.m.s. value of this current.

32. The magnetic core of a transformer is built of steel which has, for a maximum flux density of 15,000 gausses, the hysteresis loop 2. The wave form of the potential applied to this transformer is $E \sin \omega t - 0.1E \sin 3\omega t$ and is of such value that the maximum flux density is 15,000 gausses. On the assumption that the effect of eddy currents may be neglected, construct a curve showing the wave form of the exciting current. Determine the ratio of the maximum to the r.m.s. value of this current.

33. At no load with 110 volts at 60 cycles impressed on a transformer, the current is 1.3 amp. and the power is 52 watts. What will be the no-load current and power taken by a transformer similar to this in every particular, except that the cross-section of the magnetic circuit is double, when 220 volts at 60 cycles is impressed on it?

34. At no load with 110 volts at 30 cycles impressed on a transformer, the current is 1.2 amp. and the power is 53 watts, of which 14 watts is dissipated in eddy currents. What will be the current and power at no load if 220 volts at 60 cycles is impressed on this transformer?

35. The high-tension winding of a transformer consists of two coils which may be connected in series or in parallel. When these coils are connected in series across 2200 volts at 60 cycles, the current is 0.30 amp. and the power is 140 watts on open circuit. What are the no-load current and power if the coils are connected in parallel across 1100 volts at 60 cycles?

36.[1] In problem 35, what are the no-load current and power when the coils are connected in parallel across 1550 volts at 60 cycles? Assume that the core losses vary as the 1.7 power of the flux density.

37. The high-tension winding of a transformer consists of two coils which may be connected in series or in parallel. When these coils are connected in parallel across 22,000 volts at 60 cycles, the no-load current is 0.077 amp. and the power is 371 watts, 28 per cent of which is eddy-current loss. What are the no-load current and power when the coils are connected in series across 22,000 volts at 30 cycles?

38. At no load, with 460 volts impressed on the primary of a transformer, the current is 0.94 amp. and the power is 122 watts. Another transformer is similar to this one, except that the primary winding has twice as many turns and the cross-section of the magnetic circuit is one-half as great. What no-load current and power will this transformer take with 460 volts impressed on its primary winding?

39. The magnetic circuit of a transformer has a mean length of 77.3 in. and an average cross-section of 34.4 sq. in. The low-tension winding has 399 turns. Find the core loss, the no-load current, and the power factor at no load when 2300 volts at 60 cycles is impressed on the low-tension winding. Use the magnetic data given for sample A, B, C, D, or E.

40. A magnetic circuit has a mean length of 69.5 in. and an average cross-section of 30.0 sq. in. It is wound with a coil of 94 turns. A constant potential of 440 volts at 50 cycles is impressed on this coil. How long an air gap would it be necessary to cut in the magnetic circuit in order that the coil would take a current twenty times as great? What is the power factor before and after cutting the air gap? Neglect the resistance of the coil and use the magnetic data given for sample A, B, C, D, or E.

[1] Assume that the original flux density is 70 kilolines per square inch and that the relation between the flux density and the permeability for this quality of iron is expressed by

$$B = 102 - 0.017\mu$$

between B equals 45 kilolines and B equals 95 kilolines per square inch. In problems where this applies, the effect of the joints in the magnetic circuit will be neglected.

MAGNETIC DATA FOR SAMPLE E

Ordinates	Abscissae	
Flux density kilolines per square inch	Magnetizing force $H = \frac{4\pi}{10} \frac{NI}{l\,cm.}$	Core loss at 60 cycles, watts per cubic inch
40.0	2.0	0.132
53.0	3.0	0.206
61.5	4.0	0.262
67.0	5.0	0.300
73.6	7.0	0.352
80.0	10.0	0.406
86.0	15.0	0.457
89.6	20.0	0.490

This data is for a good grade of sheet steel.

For all of the problems to which this data applies assume that at the working flux density the joints in the magnetic circuit require 75 additional ampere turns. Also assume that the original ratio of eddy-current to hysteresis loss is 1:3.

When this data is used for 50 cycles assume that the core loss is 80 per cent of the loss at 60 cycles.

41. The magnetic circuit of a 5000-kv.-a. transformer has a mean length of 140 in. and an average cross-section of 613 sq. in. The number of turns in the high-tension winding is such that with the rated potential of 52,000 volts at 50 cycles impressed on this winding, 17,500 watts is supplied at no load. How many turns has the high-tension winding? What are the no-load current and power factor? Use the magnetic data given for sample A, B, C, D, or E. Assume that the core loss at 50 cycles is 80 per cent of the loss at 60 cycles.

42. If the transformer described in problem 41 is connected to a 66,000-volt, 50-cycle circuit, what will be the no-load current and power? Use the magnetic data for sample A, B, C, D, or E.

43. The magnetic circuit of a 1000-kv.-a. transformer has a mean length of 95 in. and an average cross-section of 278 sq. in. This transformer is designed to operate from a 66,000-volt, 60-cycle circuit. If the maximum flux density is to be 70,000 lines per square inch, how many turns should the high-tension winding have? What are the no-load current and power? Use the magnetic data given for sample A, B, C, D. or E.

44.[1] At no load, a 500-kv.-a. transformer takes a current of 3.35 amp. and a power of 2960 watts, when the potential impressed on the high-tension side is 11,000 volts at 60 cycles. What current and power will this transformer take at no load if 12,700 volts at 60 cycles is impressed on the high-tension winding? Assume that the core loss varies as the 1.7 power of the flux density.

45.[1] A 50-kv.-a. transformer takes a current of 0.1 amp. and a power of 641 watts at no load when 30,000 volts at 50 cycles is impressed on the high-tension winding. What current and power will this transformer take at no load if 30,000 volts at 60 cycles is impressed on the high-tension winding? Assume that the core loss varies as the 1.3 power of the frequency and the 1.7 power of the flux density.

46.[2] The magnetic core of a transformer has a mean length of 77.3 in. and a cross-section of 34.4 sq. in. How many turns should there be in the high-tension winding if the applied potential is 22,500 volts at 60 cycles? The maximum flux density to be used is 63,000 lines per square inch, at which the permeability of the iron is 1600. The core loss per cubic inch of iron at this flux density and frequency is 0.364 watt. What are the no-load high-tension current and power factor?

47.[2] The magnetic core of a 25-kv.-a. transformer has a cross-section of 17.5 sq. in. and an average length of 57.5 in. The high tension winding is designed for an applied potential of 22,000 volts at 60 cycles and for a maximum flux density in the magnetic circuit of 70,000 lines per square inch. At this flux density, the permeability is 1860 and the iron loss is 0.37 watt per cubic inch. How many turns should there be in the high-tension winding? What are the no-load current and power factor?

48.[2] A small experimental transformer has a magnetic circuit with a net cross-section of 3.4 sq. in. and a mean length of 22.5 in. Assume that the permeability of the iron is 1800. There are four

[1] Assume that the original flux density is 70 kilolines per square inch and that the relation between the flux density and the permeability for this quality of iron is expressed by

$$B = 102 - 0.017\mu$$

between B equals 45 kilolines and B equals 95 kilolines per square inch. In problems where this applies, the effect of the joints in the magnetic circuit will be neglected.

[2] Assume that, at this flux density, 75 additional ampere-turns are required because of the joints in the magnetic circuit.

coils, each of which has 232 turns, and a resistance of 0.23 ohm. (*a*) If all of the coils are connected for a 2:1 ratio of transformation, what is the magnetizing component of the no-load current when 220 volts at 60 cycles is impressed on the primary? (*b*) If the eddy-current and hysteresis losses are 50 watts, what is the no-load current?

TRANSFORMER DATA

Number	Kilovolt amperes	Type	Cycles	Potential		Turns		Magnetic circuit	
				High tension	Low tension	High tension	Low tension	Area, square inches	Average length, inches
A....	50	Core	60	22,500	2,300	...	...	31.4	77.31
B....	100	Shell	60	11,000	2,200	900	180	66	47
C....	500	Core	60	11,000	2,300	...	...	38.25	131
D....	500	Shell	25	13,200	425	558	18	276	68
E....	1,000	Shell	60	32,400	11,500	...	...	372	86.8
F....	3,333	Shell	60	55,000	6 600	733	88	318	92.8

49.[1] How many turns should there be in the high- and low-tension windings in order that the maximum flux density shall be 69,000 lines per square inch in transformer A, C, or E? What are the core loss and the ratio of the no-load to the full-load current for this transformer? Use the magnetic data given for sample A, B, C, D, or E.

50.[1] What are the no-load current and core loss of transformer B, D, or F? Use the magnetic data given for sample A, B, C, D, or E.

TRANSFORMER DATA

Number	Kilovolt-amperes	Type	Cycles	Potential		Turns		Magnetic circuit		Open circuit	
				High tension	Low tension	High tension	Low tension	Area, square inches	Average length, inches	Watts	Volt-amperes
G.........	500	Shell	60	12,700	2,300	376	68	170	66 4	3,330	25,800
H.........	1,000	Shell	60	66,000	6,600	1,240	124	278	95	9,300	60,000
I.........	5,000	Shell	50	52,000	33,000	529	336	613	140	17,500	146,000

[1] Assume that, at this flux density, 75 additional ampere-turns are required because of the joints in the magnetic circuit.

51.[1] What are the maximum flux density, the permeability, and the iron loss in watts per cubic inch for transformer G, H or I?

52.[2] What change will be produced in the core loss and in the no-load current of transformer L, . . . P, . . . or U by increasing the applied potential 10 per cent? Use the magnetic data given for sample A, B, C, or D.

53.[2] What change will be produced in the core loss and in the no-load current of transformer L, . . . P, . . . or U by increasing the frequency of the applied potential 5 per cent? Use the magnetic data given for sample A, B, C, or D.

54.[2] If transformer L, . . . P, . . . or U had been designed with 10 per cent more turns, what would have been the core loss and no-load current? Use the magnetic data given for sample A, B, C, or D.

55.[2] If transformer L, . . . P, . . . or U had been designed with 10 per cent more laminations in its core, what would have been the core loss and the no-load current? Use the magnetic data given for sample A, B, C, or D.

56. In a transformer having a ratio of transformation of $N_1:N_2$, the windings are so designed that the current densities in the primary and secondary are the same. (*a*) What is the ratio of primary to secondary resistance if both windings have the same mean length per turn? (*b*) What is this ratio if the mean length per turn of the primary is 15 per cent greater than that of the secondary? (*c*) If the current density in the primary had been 15 per cent greater than in the secondary, what would have been this ratio of the resistances if the windings had the same mean length per turn?

57. In a transformer having a ratio of transformation of $N_1:N_2$, the windings are so designed that the heating losses in the primary and secondary are the same. (*a*) What is the ratio of primary to secondary resistance if both windings have the same mean length per turn? (*b*) What is this ratio if the mean length per turn of the primary winding is 15 per cent greater than that of the secondary? (*c*) If the heating loss in the primary had been 15 per cent greater than in the secondary, what would have been this ratio if both windings had the same mean length per turn?

[1] Assume that, at this flux density, 75 additional ampere-turns are required because of joints in the magnetic circuit.

[2] Assume that the transformers are designed for a maximum flux density of 11 kilogausses.

58. What effect will be produced on the iron losses of a transformer and on the kilowatt rating, on the basis of the same total losses, by doubling the number of turns in the primary and secondary windings and halving the cross-section of the wires (*a*) when the applied potential is doubled, (*b*) when the applied potential is unchanged and the cross-section of the magnetic circuit is halved? Assume that originally the iron and copper losses are equal.

59. In a given transformer, the ratio of the iron losses to the copper losses at full load is 0.7. Another transformer with the same rating has a magnetic circuit of the same length but of 25 per cent greater cross-section, due to which the mean length of 1 turn of the winding is 10 per cent greater. Both transformers are wound with the same size of wire. The second transformer is designed so as to have the same maximum flux density as the first. What is the ratio of the total losses at full load, and what is the ratio of the iron losses to the copper losses in the second transformer at full load? Compare the amounts of copper in the two transformers. Both transformers are designed for the same potential.

60. Two transformers have identical magnetic cores and the same rated output. Both are wound for the same potential, but in the first the iron losses are 25 per cent greater than in the second, due to a higher flux density. In the first transformer, the ratio of the iron losses to the copper losses at full load is 0.7. Both transformers have the same size of wire in their windings, but the mean length of 1 turn is 5 per cent greater in the second than in the first. What is the ratio of the iron losses to the copper losses at full load in the second transformer? What is the ratio of the total losses at full load in the two transformers? Compare the amounts of copper in the two transformers. Assume that the iron losses vary as the 1.7 power of the flux density.

61. Two transformers have identical magnetic cores and the same rated output. Both are wound for the same potential, but the first has 15 per cent more turns in all of its coils than the second, due to which the mean length of 1 turn is 5 per cent greater in the first. The windings of each have the same size of wire. Assume that the iron losses vary as the 1.7 power of the flux density. The ratio of the iron losses to the copper losses at full load is 0.7 in the first transformer. What is the ratio of

the iron losses to the copper losses at full load in the second transformer? What is the ratio of the total losses at full load in the two transformers?

62. In a given transformer, the ratio of the iron losses to the copper losses at full load is 0.75. Another transformer with the same rating capacity has a magnetic core of the same length but with a cross-section 15 per cent larger. The winding of the second transformer is designed so that the iron losses are one-third greater than the iron losses of the first. The same size of wire is used in winding both transformers, but the mean length of 1 turn is 5 per cent greater in the second on account of the larger magnetic core. Assume that the iron losses vary as the 1.7 power of the flux density. Both transformers have the same potential rating. The first transformer has a full-load capacity of 100 kw. and a full-load efficiency of 97.9 per cent at unity power factor. On the basis of the same total losses, what should be the full-load rating of the second transformer? What is the ratio of the iron losses to the copper losses at full load in the second transformer?

63.[1] If transformer L, . . . P, . . . or U had been redesigned (*a*) with 5 per cent more turns, (*b*) with 5 per cent fewer, what would have been the full-load losses? Use the magnetic data given for sample A, B, C, or D.

64.[1] If transformer L, P, or U had been redesigned (*a*) with 5 per cent more laminations in its core, (*b*) with 5 per cent fewer, what would have been the full-load losses? Use the magnetic data given for sample A, B, C, or D.

65. Three equal 10:1 transformers, each of 100-kv.-a. capacity, are arranged with both the primaries and secondaries in Y to receive power from a 3-phase, 2200-volt circuit. The losses in each transformer at full load are 1960 watts of which 940 are core losses. If these transformers are connected in delta to this circuit, what power will they deliver without exceeding their full-load heating losses? Assume that the iron losses vary as 1.7 power of the flux density.

66. The name plate of a transformer gives the following data: 100 kv.-a., 6600:220 volts, 25 cycles. The percentage distribution of the losses at full load is: copper loss, 1.0 per cent; eddy-current loss, 0.3 per cent; hysteresis loss, 0.8 per cent. If the insulation of the transformer will safely stand double potential, what should be its rating on the basis of the

[1] Assume that the transformers are designed for a maximum flux density of 11 kilogausses.

same total heating losses when taking power from an 11,000-volt, 50-cycle circuit?

67. The name plate of a transformer gives the following data: 500 kv.-a. 13,200:400 volts, 50 cycles. At full load, the copper loss is 4600 watts and the iron loss is 2800 watts. Of the latter, 22 per cent is due to eddy currents. If this transformer is to receive power from an 11,000-volt, 60-cycle circuit, what should be its full-load rating on the basis of the same total heating losses?

68. On the basis of the same total heating losses, what should be the rated kilovolt-ampere capacity of transformer L, . . . P, . . . or U when the applied potential is (*a*) 15 per cent greater than normal, (*b*) 15 per cent less than normal? Assume that normally the hysteresis loss is three times the eddy-current loss.

69. On the basis of the same total heating losses, what should be the rated kilovolt-ampere capacity of transformer L, . . . P, . . . or U when the frequency of the applied potential is (*a*) 10 per cent greater than normal, (*b*) 10 per cent less than normal? Assume that normally the hysteresis loss is three times the eddy-current loss.

70. On the basis of the same total heating losses, what should be the rated kilovolt-ampere capacity of transformer L, . . . P, . . . or U when both the applied potential and its frequency are (*a*) 10 per cent greater than normal, (*b*) 10 per cent less than normal? Assume that normally the hysteresis loss is three times the eddy-current loss.

71. A 100-kv.-a. transformer takes 1050 watts on open circuit and 950 watts on short circuit with full-load current in the windings. What is its efficiency when delivering 10 per cent overload current at 0.88 power factor?

72. What is the efficiency of transformer L, . . . P, . . . or U when delivering its rated kilovolt-amperes (*a*) at unity power factor, (*b*) at 0.85 power factor?

73.[1] What is the efficiency of transformer L, . . . P, . . . or U when delivering its rated current (*a*) at unity power factor, (*b*) at 0.85 power factor, if the terminal potential is (1) 10 per cent greater than normal, (2) 10 per cent less than normal? Use the magnetic data given for sample A, B, C, or D.

74. A 10-kw. lighting transformer takes 122 watts on open circuit and 178 watts on short circuit with full-load current in

[1] Assume that the transformers are designed for a maximum flux density of 11 kilogausses.

the windings. This transformer is connected to the supply circuit continuously. It delivers its rated load, however, during but 6 hours each day and is idle the remaining 18 hours. What is the all-day efficiency?

75. A 100-kv.-a. transformer supplies a lighting and power load. The iron loss is 1010 watts, and the copper loss is 1004 watts with full-load current. This transformer is connected to the supply circuit continuously. During 7 hours, the load is 60 kw. at 0.75 power factor, and for the remaining 3 hours of the working day the load is 80 kw. at 0.83 power factor. The rest of the time no load is supplied. What is the all-day efficiency?

76. A 500-kv.-a. power transformer is connected to the supply circuit for 12 hours each day. The iron loss is 3330 watts, and the copper loss is 4680 watts with full-load current. During 5 hours, it delivers 400 kw. at 0.80 power factor, and during 4 hours, 250 kw. at 0.75 power factor. The remaining hours it is idle. What is the all-day efficiency?

77. Calculate the all-day efficiency of transformer L, . . . P, . . . or U for the following load curve:

1 hour.......	120 per cent of rated kilovolt-amperes at 0.85 power factor
3 hours.......	100 per cent of rated kilovolt-amperes at 0.80 power factor
2 hours.......	60 per cent of rated kilovolt-amperes at 0.70 power factor
4 hours.......	30 per cent of rated kilovolt-amperes at 0.60 power factor
14 hours.......	5 per cent of rated kilovolt-amperes at 0.98 power factor

78. Calculate the all-day efficiency of transformer L, . . . P, . . . or U for the following load curve:

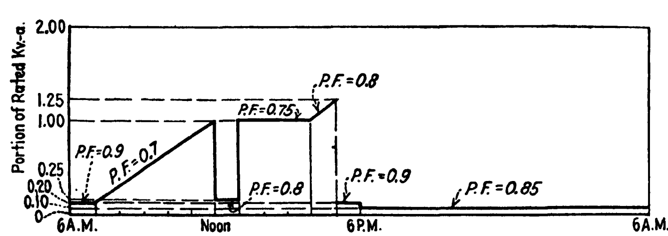


FIG. 1.

79.[1] Compute the effect on the all-day losses of having the applied potential (*a*) 10 per cent above normal, (*b*) 10 per cent below normal, when transformer L, . . . P, . . . or U is operating on the following load curve:

[1] Assume that normally the hysteresis loss is three times the eddy-current loss.

1 hour.............	100 per cent of rated kilowatts at 0.8 power factor
4 hours............	75 per cent of rated kilowatts at 0.75 power factor
3 hours............	50 per cent of rated kilowatts at 0.70 power factor
2 hours............	25 per cent of rated kilowatts at 0.60 power factor
14 hours............	5 per cent of rated kilowatts at 0.97 power factor

80.[1] Compute the effect on the all-day losses of having the frequency of the applied potential (*a*) 5 per cent above normal, (*b*) 5 per cent below normal when transformer L, ... P, . . . or U is operating on the load curve given in problem 79.

81. What are the equivalent resistance and reactance of transformer L, . . . P, . . . or U (*a*) on the high tension side, (*b*) on the low-tension side?

82. What per cent are the equivalent resistance, equivalent reactance, and core loss of transformer L, . . . P, . . . or U?

83. What are the resistances of the primary and secondary windings of transformer L, . . . P, . . . or U? Assume that the primary and secondary copper losses are equal when the transformer delivers its rated kilovolt-amperes, and neglect the exciting current.

84. If, during the short-circuit test on transformer L, . . . P, . . . or U, frequency is (*a*) 5 per cent greater (*b*) 5 per cent less than normal. what will be the current and power for the same value of the applied potential?

85. A 500-kv.-a., 11,000:2300-volt, 60-cycle transformer has primary and secondary resistances of 0.81 and 0.0358 ohm, respectively, and primary and secondary leakage reactances of 3.7 ohms and 0.162 ohm, respectively. With the low-tension winding short circuited, what potential should be impressed on the high-tension winding so that the current will have its full-load value? Neglect the no-load current.

86. A 7.5-kv.-a., 2080:208-volt, 60-cycle transformer has the following constants:

$r_1 = 7.53$ ohms $\qquad x_1 = 14.2$ ohms

$r_2 = 0.0662$ ohm $\qquad x_2 = 0.128$ ohm

The core loss with 208 volts impressed on the secondary is 200 watts. Neglect the exciting current. (*a*) What is the regulation of this transformer for full-load current at 0.8 power factor? (*b*) What is the efficiency of the transformer for this load?

[1] Assume that normally the hysteresis loss is three times the eddy-current

87. A 50-kv.-a., 30,000:440-volt, 50-cycle transformer has the following constants:

$r_1 = 120$ ohms $x_1 = 428$ ohms
$r_2 = 0.0258$ ohm $x_2 = 0.092$ ohm

The iron loss at the rated potential is 641 watts. Neglect the exciting current. (*a*) What is the regulation of this transformer for a load of 40 kw., at 0.75 power factor? (*b*) What is the efficiency of the transformer for this load?

88. A 1000-kv.-a., 66,000:6600-volt, 60-cycle transformer has the following constants:

$r_1 = 16.9$ ohms $x_1 = 115$ ohms
$r_2 = 0.157$ ohm $x_2 = 0.95$ ohm

The iron loss at the rated potential is 9,200 watts. Neglect the exciting current. (*a*) What is the regulation of this transformer for a load of 850 kw. at 0.80 power factor? (*b*) What is the efficiency of the transformer for this load?

89. A 5000-kv.-a., 52,000:33,000-volt, 50-cycle transformer has the following constants:

$r_1 = 1.56$ ohms $x_1 = 13.4$ ohms
$r_2 = 0.55$ ohm $x_2 = 6.4$ ohms

The iron loss at the rated potential is 17,200 watts. Neglect the exciting current. (*a*) What is the regulation of this transformer for a load of 4500 kw. at 0.80 power factor? (*b*) What is the efficiency of the transformer for this load?

TRANSFORMER DATA

Number	Kilovolt-amperes	Type	Cycles	High tension	Low tension	Short circuit		Open circuit		
						Watts	Volt-amperes	Volts	Amperes[1]	Watts
J......	25	Core	60	22,000	440	371	1,700	1,020	1.136	351
K......	50	Core	50	30,000	440	641	3,000	1,360	1.665	665
B......	100	Shell	60	11,000	2,200	940	3,750	310	9.1	1,000
C......	500	Core	60	11,000	2,300	2,960	7,710	345	45.5	3,375
D......	500	Shell	25	13,200	425	2,500	16,000	1,100	37.9	4,600
H......	1,000	Shell	60	66,000	6,600	9,300	60,000	3,240	15 15	7,490
F......	3,333	Shell	60	55,000	6,600	13,940	161,000	2,350	60.6	18,850
I......	5,000	Shell	50	52,000	33,000	17,500	146,000	1,800	151.5	27,000

[1] Full-load current.

90. Calculate (*a*) the regulation[1] and (*b*) the efficiency of the transformer J for a load of 22 kw. at 0.85 power factor and rated potential.

91. Calculate (*a*) the regulation[1] and (*b*) the efficiency of the transformer K for a load of 40 kw. at 0.78 power factor and rated potential.

92. Calculate (*a*) the regulation[1] and (*b*) the efficiency of the transformer B for a load of 100 kw. at 0.90 power factor and rated potential.

93. Calculate (*a*) the regulation[1] and (*b*) the efficiency of the transformer C for a load of 460 kw. at 0.91 power factor and rated potential.

94. Calculate (*a*) the regulation[1] and (*b*) the efficiency of the transformer D for a load of 500 kw. at 0.93 power factor and rated potential.

95. Calculate (*a*) the regulation[1] and (*b*) the efficiency of the transformer H for a load of 1100 kw. at unity power factor and rated potential.

96. Calculate (*a*) the regulation[1] and (*b*) the efficiency of the transformer F for a load of 3500 kw. at unity power factor and rated potential.

97. Calculate (*a*) the regulation[1] and (*b*) the efficiency of the transformer I for a load of 5100 kw. at 0.92 power factor and rated potential.

98. Compute the regulation[1] and efficiency of transformer L, . P, . . . or U when it delivers its rated kilovolt-amperes at 0.80 power factor.

99. Compute the regulation and efficiency of a transformer which has an equivalent resistance, an equivalent reactance, and a core loss of 0.5, 5.6, and 0.5 per cent, respectively, when delivering its rated kilowatts at 0.9 power factor.

100. A 500-kv.-a., 13,200:425-volt, 25-cycle transformer has primary and secondary resistances of 1.6 ohms and 0.00166 ohm, respectively, and primary and secondary leakage reactances of 14.5 ohms and 0.0151 ohm, respectively. At no load with 425 volts impressed on the low-tension winding the power is 2.5 kw. and the kilovolt-amperes are 16.0. Neglect any change in the exciting current with change in the load. Calculate (*a*) the regulation and (*b*) the efficiency of this transformer when 400 kw. is supplied to the high-tension winding at 13,200 volts

[1] Neglect the exciting current.

and 0.75 power factor. Use the complete transformer diagram in the solution of this problem. (*c*) Calculate the regulation and efficiency of this transformer for the same load on the assumption that the no-load current is negligible and that the core losses are constant.

101. The following data are given concerning a 1000-kv.-a., 66,000:6600-volt, 60-cycle transformer:

	No load	Short circuit
Current	9.1	15.15[1]
Potential	6,600	3,240
Power	9,300	7,490

[1] Full-load current.

Assume that the primary and secondary resistances are equal when reduced to the same side and that the primary and secondary leakage reactances are similarly equal. Assume that the magnetizing current varies as the generated e.m.f. and that the core loss varies as the square of this e.m.f.

Calculate (*a*) the regulation and (*b*) the efficiency when the secondary delivers full-load current at 0.80 power factor and a terminal potential of 6680 volts. (*c*) Calculate the regulation and efficiency of this transformer for the same load on the assumption that the no-load current is negligible and that the core losses are constant.

102. (*a*) Compute the regulation and efficiency of transformer L, . . . P, . . . or U when it delivers its rated kilovolt-amperes on the high-tension side at 0.80 power factor. Assume that the core loss and the exciting current are constant and that the copper losses in the two windings are equal during the short-circuit test. Also, assume that a test shows that the leakage reactance of the high-tension winding is 50 per cent greater than the leakage reactance of the low-tension winding. (*b*) Compute the regulation and efficiency of the same transformer for the same load on the assumption that the core loss is constant and that the exciting current is negligible.

103. (*a*) Compute the regulation and efficiency of transformer L, . . . P, . . . or U when it delivers its rated kilovolt-amperes on the high-tension side at 0.80 power factor. Assume that the core loss and the exciting current both vary as the square of the core flux and that the copper losses in the two

windings are equal during the short-circuit test. Also, assume that a test shows that the leakage reactance of the high-tension winding is 50 per cent greater than the leakage reactance of the low-tension winding when the latter is referred to the high-tension side. (*b*) Compute the regulation and efficiency of the same transformer for the same load on the assumption that the core loss is constant and that the exciting current is negligible.

104. Compute the phase angle between the primary and secondary currents when transformer L, . . . P, . . . or U delivers its rated kilovolt-amperes (*a*) at 0.80 power factor lagging, (*b*) at 0.80 power factor leading. Assume that the exciting current is constant.

105. A transformer has a secondary resistance of 0.25 per cent, a secondary reactance of 3.0 per cent, an exciting current of 3.1 per cent, and a power factor at no load of 12.0 per cent. Compute the angle between the primary and secondary currents when this transformer delivers its rated kilovolt-amperes at 0.80 power factor (*a*) to an inductive load, (*b*) to a condensive load.

106. Compute the phase relation of the primary and secondary terminal potentials when transformer L, . . . P, . . . or U delivers its rated kilovolt-amperes at 0.80 power factor (*a*) to an inductive load, (*b*) to a condensive load. (1) Assume that the exciting current is constant. (2) Neglect the exciting current.

107. Compute the self, mutual, and leakage inductances of the primary and secondary windings at normal saturation for transformer L, . . . P, . . . or U. (*a*) Assume that the leakage coefficient is the same for each of the windings. (*b*) Assume that the leakage coefficient of the primary is 50 per cent greater than the leakage coefficient of the secondary.

108. A 100-kv.-a., 11,000:2200-volt, 60-cycle transformer has primary and secondary resistances of 6.0 ohms and 0.24 ohm, respectively, and primary and secondary leakage reactances of 16 ohms and 0.64 ohm, respectively. What is the maximum percentage change that can occur in the mutual flux from no-load to full-load current? At what power factor would this occur? Neglect the no-load current.

109. (*a*) What is the ratio of the primary and secondary leakage flux linkages when transformer L, . . . P, . . . or U delivers its rated kilovolt-amperes? (*b*) What is the ratio of the primary leakage flux linkage to its mutual flux linkage when this transformer delivers its rated kilovolt-amperes at 0.80 power

factor (1) to an inductive load, (2) to a condensive load? Neglect the exciting current and assume that the primary and secondary resistances and leakage reactances are equal when referred to the same side.

110. Two transformers of the same design, L, . . . P, . . . or U, together with a third transformer *W*, are connected as shown in Fig. 2, so that a full-load heat test may be made. Assume that during the test the equivalent impedance drop in *W* is 5 per cent and that the angle of this equivalent impedance is the same as the angle of the equivalent inpedances of the transformers under test. Also, assume that the leakage in the transformer under test is equally divided between the primary and secondary. What should be the ratio of transformation of the transformer *W*? If the core loss in the transformers under test varies as the square of the flux density in the core, what is the core loss in each transformer?

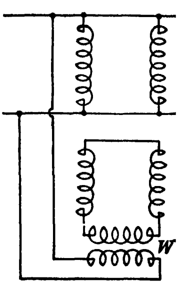


FIG. 2

111. The high- and low-tension windings of transformer L, . . . P, . . . or U are connected in series, as shown in Fig. 3. If the high-tension winding (H.T.) is delivering its rated kilovolt-amperes at 0.8 power factor, lagging, as shown by the readings of the instruments *V*, *I*, and *P*, what is the potential across the terminals *a* and *b*?

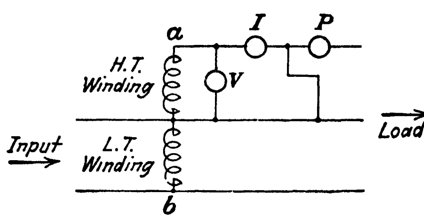


FIG. 3.

112. The resistance of the high-tension winding *ac* of a 2:1 autotransformer is 0.072 ohm, and that of the low-tension winding *bc* is 0.035 ohm. The leakage reactance of the low-tension winding is 0.106 ohm, and that of the remaining portion of the winding *ab* is 0.108 ohm. If an e.m.f. of 12 volts at the rated frequency is impressed on the high-tension winding and the low-tension winding is short-circuited, what will be the current and power taken from the line? See Fig. 4.

113. The resistance of the high-tension winding *ac* (see Fig. 4) of a 25-kv.-a., 550:110-volt, autotransformer is 0.0682 ohm, and that of the low-tension winding *bc* is 0.0042 ohm.

The leakage reactance of the winding *ab* is 0.214 ohm, and that of the low-tension winding is 0.0132 ohm. If the winding *ab* is short circuited, what percentage of the rated potential should be applied to the low-tension winding *bc* in order that full-load current should exist in the windings? What power would be supplied?

114. The resistance of the high-tension winding *ac* (see Fig. 4) of a 50-kv.-a., 440:110-volt autotransformer is 0.02156 ohm, and that of the low-tension winding *bc* is 0.00216 ohm. The leakage reactance of the winding *ab* is 0.068, and that of the low-tension winding is 0.00756 ohm. If the high-tension winding is short circuited, what potential should be impressed on the low-tension winding in order that there will be full-load current in the windings? What power would be supplied?

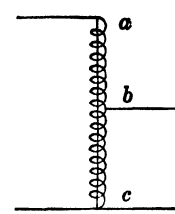


Fig. 4.

115. Calculate the regulation of the autotransformer described in problem 113 for a load of 22 kw. at 0.80 power factor on the low-tension side. If the core loss at the rated potential is 288 watts, what is the efficiency of the transformer at this load?

116. Calculate the regulation of the autotransformer described in problem 114 for a load of 46 kw. at 0.87 power factor on the low-tension side. If the core loss is 512 watts at the rated potential, what is the efficiency of the transformer at this load?

Autotransformer Data

Number	Kilovolt-amperes	Potential	Short circuit			Core loss at rated potential
			Watts	Amperes[1]	Volts[1]	
A	10	155:110	168	64.5	7 2	122
B	20	440:220	320	45.5	20 2	264
C	25	660:220	340	37.9	29 0	371
D	50	550:110	620	91.0	25.0	664
E	100	6,600:440	940	15.15	275.0	980
F	500	11,000:300	3,850	45.5	460.0	2,980

[1] The low-tension winding is short circuited, and potential is applied to the high-tension winding so that there is full-load current in the windings.

117. Calculate the regulation of the autotransformer A for a load of 10 kw. at unity power factor on the low-tension side. What is the efficiency of the transformer at this load?

118. Calculate the regulation of the autotransformer B for a load of 16 kw. at 0.78 power factor on the high-tension side. What is the efficiency of the transformer at this load?

119. Calculate the regulation of the autotransformer C for a load of 22 kw. at 0.80 power factor on the high-tension side. What is the efficiency of the transformer at this load?

120. Calculate the regulation of the autotransformer D for a load of 55 kw. at unity power factor on the low-tension side. What is the efficiency of the transformer at this load?

121. Calculate the regulation of the autotransformer E for a load of 93 kw. at 0.87 power factor on the low-tension side. What is the efficiency of the transformer at this load?

122. Calculate the regulation of the autotransformer F for a load of 510 kw. at 0.90 power factor on the low-tension side. What is the efficiency of the transformer at this load?

123. Calculate the regulation and efficiency of the autotransformer G, H or I when it delivers its rated kilovolt-amperes on the high-tension side at 0.80 power factor to an inductive load.

124. Calculate the regulation and efficiency of the autotransformer G, H or I when it delivers its rated kilovolt-amperes on the low-tension side at 0.80 power factor to an inductive load.

125. If the high-tension winding of the autotransformer E is short circuited, what potential should be applied to the low-tension winding so that there will be full-load current in the windings?

126. If the high-tension winding of the autotransformer F is short circuited, what potential should be applied to the low-tension winding so that there will be full-load current in the windings?

127. If the high-tension winding of the autotransformer G, H, or I is short circuited, what potential should be applied to the low-tension winding so that there will be rated current in the windings?

128. An induction regulator is connected in a 2300-volt circuit, as shown in Fig. 5. With no load on the line and with 2300 volts impressed on the circuit, as shown in the figure, the potential measured from *a* to *c* is 2550 volts. If the winding *bc* is short circuited and a reduced potential of 460 volts is impressed on the winding *ab*, the line current *oa* is 15 amp. and the power supplied is 2.2 kw. (*a*) When the station supplies 250 kw. at 0.78 power factor and a potential of 2300 volts at *ab*, what is

the line potential at *ac*? (*b*) This regulator is adjusted to reduce the potential so that with no load on the line and with 2300 volts impressed on the circuit (at *ab*), the potential at *ac* is 2050. The short-circuit data are unchanged. What is the potential at *ac* when the station supplies 300 kw. at a leading power factor of 0.92 and a line potential of 2300 volts at *ab*?

129. An induction regulator is connected in a 6600-volt circuit, as shown in Fig. 5. With no load on the line and with 6600 volts impressed on the circuit (at *ab*), the potential measured from *a* to *c* is 7370 volts. If the winding *bc* is short circuited and a reduced potential of 1060 volts is impressed on the winding *ab*, the line current (in *oa*) is 8.6 amp., and power supplied is 4.2 kw. (*a*) When the station supplies 430 kw. at 0.80 power factor and a potential of 6600 volts at *ab*, what is the line potential at *ac*? (*b*) This regulator is adjusted to reduce the potential so that with no load on the line and with 6600 volts impressed on the circuit (at *ab*) the potential at *ac* is 5850 volts. The short-circuit data are unchanged. What is the potential at *ac* when the station supplies a line current (in *oa*) of 81 amp. at a leading power factor of 0.83 and a line potential of 6600 volts at *ab*?

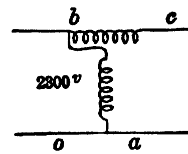


FIG. 5.

130. A small experimental transformer has 4 equal coils which may be interconnected in different ways. In the first case, all of the coils are connected to form a regular transformer with a ratio of transformation of 2:1; and, in the second case, they are connected to form an autotransformer with the same ratio of transformation. When connected as a regular transformer, with the low-tension winding short circuited, the current, potential, and power, measured on the high-tension side, are 8 amp., 52 volts, and 59 watts, respectively. On open circuit, with 220 volts impressed on the high-tension side, the core loss is 26 watts. Assume that the paths of the leakage flux are the same for each connection. Compare (*a*) the regulations and (*b*) the efficiencies of this transformer for the two cases given above for a load of 1.5 kw. at 0.9 power factor and 110 volts on the low-tension side.

131. Two transformers, one connected as a regular and the other as an autotransformer, have identical magnetic cores and the same amount of copper in their windings. Each of the

transformers gives a ratio of transformation of 330:220 volts, and the windings are so designed that the core losses in each are 122 watts when 330 volts is impressed on their primaries. The primary and secondary resistances of the regular transformer are 0.097 and 0.0431 ohm, respectively. The resistance of the autotransformer measured on the low-tension side is also 0.0431 ohm. The leakage reactance of the primary winding of the regular transformer is 0.37 ohm. Assume that all of the windings have the same mean length per turn and that the leakage reactance of the coils vary as the square of the number of turns. (*a*) On the basis of the same total heating losses, what is the ratio of the outputs of these two transformers? (*b*) What is the regulation and efficiency of each transformer for a load of 10 kw. at 0.87 power factor and 220 volts?

132. Two transformers, one connected as a regular and the other as an autotransformer, have identical magnetic cores and the same amount of copper in their windings. Each of these transformers gives a ratio of transformation of 330:110 volts, and the windings are so designed that the core losses of each are 371 watts when 330 volts is impressed on their primaries. The primary and secondary resistances of the regular transformer are 0.0306 and 0.0034 ohm, respectively. The resistances of the autotransformer measured on the high- and low-tension sides are 0.017 and 0.0034 ohm, respectively. The equivalent leakage reactance of the regular transformer referred to the high-tension side is 0.202 ohm. Assume that the leakage reactances of the windings vary as the square of the number of turns in them. (*a*) If the high-tension winding of the regular transformer has 186 turns, how many turns are there in each of the other windings of the regular and the autotransformer? (*b*) The regular transformer is rated to deliver 25 kw. at 110 volts. If the losses at full load are the same for both transformers, what is the kilovolt-ampere rating of the autotransformer? (*c*) What is the regulation and efficiency of each transformer when it is delivering its rated full-load current at 0.83 power factor and its rated potential?

133. Two transformers, one connected as a regular, and the other as an autotransformer, have identical magnetic cores and the same amount of copper in their windings. Each of these transformers gives a ratio of transformation of 550:220 volts, and the windings are so designed that the volts per turn are

the same for each. With 25 volts impressed on the high-tension winding of the regular transformer, and with the low-tension winding short circuited, the current and power are 91 amp. and 665 watts. At the rated potential, the core loss in the regular transformer is 641 watts. Assume that the resistances and leakage reactances of all of the windings vary as the square of the number of turns in them.

(*a*) The regular transformer is rated to deliver 50 kv.-a. at 220 volts. If the losses at full load are the same for both transformers, what is the kilovolt-ampere rating of the autotransformer?

(*b*) What are the regulation and efficiency of each transformer when it is delivering its rated full-load power at 0.9 power factor?

134. Two transformers, one connected as a regular and the other as an autotransformer, have identical magnetic cores and the same amount of copper in their windings. Each of these transformers gives a ratio of transformation of 440:110 volts, and the windings are so designed that the volts per turn are the same for each. With 14 volts impressed on the high-tension winding of the regular transformer, and with the low-tension winding short circuited, the current is 227 amp. and the power is 1004 watts. The core loss of this transformer at rated impressed potential is 1010 watts. Assume that the resistances and leakage reactances of all of the windings vary as the square of the number of turns in them.

(*a*) The regular transformer is rated to deliver 100 kv.-a. at 110 volts. If the losses at full load are the same for both transformers, what is the kv.-a. rating of the auto-transformer?

(*b*) What are the regulation and efficiency of each transformer for full-load current at 0.80 power factor?

135. If transformer L, . . . P, . . . or U is connected as an autotransformer, what will be its regulation and efficiency when delivering its rated kilovolt-amperes at 0.80 power factor to an inductive load? With rated kilovolt-amperes, the losses are the same as when operated as a regular transformer at full load.

136. Transformer L, . . . P, . . . or U is connected as an autotransformer. (*a*) With the low-tension winding short circuited, what potential should be applied to the high-tension winding so that rated current will flow in the windings? (*b*) With the high-tension winding short circuited, what potential should be applied to the high-tension winding so that rated current will flow in the windings?

137. A 10- and a 25-kv.-a. transformer, each of which has a ratio of transformation of 5:1, have their primaries connected in parallel across an 1100-volt circuit. Their secondaries are also connected in parallel and supply 152 amp. at 0.84 power factor to an induction motor. Referred to the secondary sides, the equivalent resistances are 0.0865 and 0.0272 ohm, respectively, and the equivalent reactances are 0.143 and 0.0856 ohm, respectively.

What current does each transformer take from the circuit? Compare these currents with their rated full-load values.

138. The following short-circuit data are given on two 100-kv.-a., 11,000:460-volt transformers:

Type	Amperes[1]	Volts	Watts
Core	9.1	265	1,004
Shell	9.1	310	1,000

[1] Full-load current.

These transformers are connected in parallel on both the high- and low-tension sides and supply a load of 186 kw. at 0.93 power factor. What per cent of its full-load current does each transformer supply?

139. The following short-circuit data are given on two transformers which have a ratio of transformation of 11,000:2300 volts:

Kilovolt-amperes	Type	Amperes[1]	Volts	Watts
100	Core	9.1	265	1,004
500	Core	45.5	345	3,375

[1] Full-load current.

These transformers are connected in parallel on both the high- and low-tension sides and supply a total current of 293 amp. at 0.92 power factor on the low-tension side. What is the current in each transformer? Compare the copper losses with their full-load values.

140. The following short-circuit data are given on two 500-kv.-a., 11,000:2300-volt transformers:

Type	Amperes[1]	Volts	Watts
Core	45.5	345	3,375
Shell	45.5	345	4,680

[1] Full-load current.

These transformers are connected in parallel on both the high- and low-tension sides and supply a total current of 452 amp. at 0.95 power factor on the low-tension side. What current does each transformer supply?

141. The following short-circuit data are given on three 66,000:6600-volt transformers:

Number	Kilovolt-amperes	Type	Amperes[1]	Volts	Watts
A	1,000	Shell	15.15	3,240	7,490
B	3,333	Shell	50.5	2,820	18,850
C	5,000	Shell	75.8	3,600	27,000

[1] Full-load current.

These transformers are connected in parallel on both their high- and low-tension sides and supply a load of 9200 kw. at a power factor of 0.93 and their rated potential. Compare the division of the total current between the transformers with their ratings.

142. The following short-circuit data are given on three 11,000:460-volt transformers:

Kilovolt-amperes	Type	Amperes[1]	Volts	Watts
100	Core	9.1	265	1,004
500	Shell	45.5	917	4,600
500	Core	45.5	345	3,375

[1] Full-load current.

These transformers are connected in parallel on both the high- and low-tension sides and supply a load of 754 kw. at 0.88 power factor and their rated potentials. What current does each transformer supply? Compare the copper loss in each transformer with the copper loss at full load.

143. Consider the transformers B and C, described in problem 141. The high-tension windings receive power from the same 66,000-volt circuit, while the low-tension windings deliver power to independent circuits. Each transformer delivers its rated full-load current, the first at unity power factor, and the second at 0.88 power factor. If the low-tension circuits are now connected in parallel, what is the current in each transformer?

Compare these currents with their full-load values. Assume that the currents taken by the low-tension circuits and the power factors at which they operate remain unchanged.

144. The following short-circuit data are given on three 38,100:2300-volt transformers:

Kilovolt-amperes	Amperes	Volts	Watts
500	217	105	4,320
1000	434	102	6,880
1000	434	153	6,540

These transformers are connected to the same high-tension circuit but deliver power to independent feeders. Each transformer delivers its rated kilovolt-amperes, the first at 0.96, the second at 0.80, and the third at 0.66 power factor. If the low-tension feeders are now connected in parallel, what kilovolt-amperes does each transformer deliver? Assume that the load on each feeder remains unchanged.

145. The following data are given on three 13,200:2300-volt transformers:

Kilovolt-amperes	Per cent resistance	Per cent reactance
100	1.16	2.04
500	0.86	4.54
500	0.78	4.22

These transformers are connected to the same hign-tension circuit but deliver power to independent feeders. Each transformer delivers its rated kilovolt-amperes, the first at unity, the second at 0.80, and the third at 0.60 power factor. If the low-tension feeders are now connected in parallel, what kilovolt-amperes does each transformer deliver? Assume that the load on each feeder remains unchanged.

146. The following short-circuit data are given on three 63,500:12,000-volt transformers:

Kilovolt-amperes	Amperes	Volts	Watts
5,000	417	1,510	35,500
3,333	278	500	18,470
4,500	375	916	26,750

These transformers are operating in parallel on both their high- and low-tension sides and are delivering a total load of 8000 kv.-a. at 0.80 power factor. (*a*) What is the kilovolt-amperes output of each transformer? (*b*) If the short-circuit watts be disregarded and if it be assumed that the angle of the equivalent impedance is the same for each transformer, what is the computed value of the kilovolt-ampere output of each transformer?

147. The following short-circuit data are given on three 69,200:12,000-volt transformers:

Kilovolt-amperes	Amperes	Volts	Watts
3,333	278	1,050	20,660
3,333	278	500	18,470
5,000	417	1,510	35,500

These transformers are operating in parallel on both their high- and low-tension sides. (*a*) What is the greatest kilovolt-ampere load that these transformers can deliver without overloading any one? (*b*) If the short-circuit watts be disregarded and if it be assumed that the angle of the equivalent impedance is the same for each transformer, what is the computed value of the greatest kilovolt-ampere load that these transformers can deliver without overloading any one?

148. The following short-circuit data are given on four 95,000: 24,000-volt transformers:

Kilovolt-amperes	Amperes	Volts	Watts
3,333	139	1,010	18,200
3,333	139	2,100	20,800
4,500	188	1,840	26,700
5,000	208	2,980	35,600

What combination of these transformers when operating in parallel on both the high- and low-tension sides will deliver the greatest kilovolt-ampere load without overloading any one?

149. The following data are given on two 14,300:11,000-volt transformers:

Kilovolt-amperes	Per cent equivalent resistance	Per cent equivalent reactance
4,500	0.594	7.64
5,000	0.710	12.6

If these transformers are operating in parallel on both their high- and low-tension sides, how will they divide a load of 8000 kilovolt-amperes between them?

150. The following data are given on three 11,000:2300-volt transformers:

Kilovolt-amperes	Per cent equivalent resistance	Per cent equivalent reactance
1,000	0.688	4.36
3,333	0.618	8.80
5,000	0.608	7.84

What is the greatest kilovolt-ampere load that these transformers can deliver, when operating in parallel on both their high- and low-tension sides, without overloading any one? Is it possible to increase this permissible load by disconnecting one of the transformers?

151. Two 50-kw. transformers are connected in parallel on both the high- and low-tension sides. Their constants are given in the following table:

Open-circuit potential		High tension		Low tension	
High tension	Low tension	r_1	x_1	r_2	x_2
22,500	2,310	61.6	110	0.661	1.16
22,400	2,320	61.6	110	0.661	1.16

They are alike except for the difference in their ratios of transformation. These transformers supply a combined load of 93 kw. at 0.89 power factor on the low-tension side at a terminal potential of 2300 volts. What is the current in each transformer?

152. The following data are given on two transformers which are operating with both their high- and low-tension windings in parallel:

Kilovolt-amperes	Type	Rated open-circuit potential		Short circuit		
		High tension	Low tension	Amperes[1]	Volts	Watts
100	Core	11,000	440	9.1	265	1,004
500	Shell	13,200	520	37.9	1,100	4,600

[1] Full-load current.

The ratios of transformation are slightly different. These transformers take a combined power of 460 kw. at 0.90 power factor from an 11,000-volt circuit. (*a*) What is the current in each transformer? (*b*) If the ratios of transformation are made equal by the removal of a few turns from the high-tension winding of the 500-kw. transformer, what is the current taken by each transformer for this load? Assume that the short-circuit data would be unchanged.

153. The following data are given on two transformers which are operating in parallel on both the high- and low-tension sides:

Kilovolt-amperes	Type	Rated open-circuit potential		Short circuit		
		High tension	Low tension	Amperes[1]	Volts	Watts
500	Core	13,200	2,340	37.9	413	3,375
500	Shell	12,700	2,170	39.4	332	4,680

[1] Full-load current.

The ratios of transformation are slightly different. These transformers take a combined power of 960 kw. at 0.92 power factor from a 12,800-volt circuit. (*a*) What is the current in each transformer? (*b*) If the ratios of transformation are made equal by removing a few turns from the high-tension winding of the shell-type transformer, what is the current taken by each transformer for this load? Assume that the short-circuit data would be unchanged.

154. Consider the transformers described in problem 137. They are operating in parallel on both the high- and low-tension

sides. (*a*) What are the least values of resistance and reactance that should be added to each transformer on the low-tension side in order that the currents supplied by the transformers shall be in phase and in proportion to their capacities? (*b*) For a given load on the transformers, compare the total heating in the transformers and reactors with that in the transformers alone before the addition of the reactors.

155. Consider the transformers described in problem 138. They are operating in parallel on both the high- and low-tension sides. (*a*) Compare the sum of their rated outputs with the kilovolt-ampere load which they can deliver without overloading either of them. (*b*) A reactor of negligible resistance is added on the low-tension side of the transformer of such value that the resultant impedance volts of the transformer and reactor on short circuit with full-load current is the same as that of the other transformer alone when it also carries full-load current. What is the impedance of this reactor? By what amount can the combined output of the transformers be increased by the addition of this reactor without overloading either transformer?

156. Consider the transformers described in problem 139. They are operating in parallel on both the high- and low-tension sides. (*a*) Compare the sum of their rated outputs with the greatest kilovolt-ampere load that they can deliver without overloading either of them. (*b*) A reactor of negligible resistance is added on the low-tension side of one transformer of such value that the resultant impedance volts of the transformer and reactor on short circuit with full-load current is the same as that of the other transformer alone when it also carries full-load current. What is the impedance of this reactor? By what amount can the combined output of the transformers be increased by the addition of this reactor without overloading either transformer?

157. The following data are given on two transformers which are operating in parallel on both their high- and low-tension sides:

Kilovolt-amperes	Type	Potential		Short circuit		
		High tension	Low tension	Volts	Amperes[1]	Watts
1,000	Shell	66,000	6,600	3,360	15.15	7,490
3,333	Shell	66,000	6,600	2,780	50.5	18,850

[1] Full-load current.

These transformers are delivering a combined load of 4333 kv.-a. at 6600 volts. A reactor of negligible resistance is added in series with one of these transformers on the low-tension side, so that they divide this load in proportion to their ratings. Assume that this does not effect the low-tension potential. (*a*) What per cent of its rated capacity is the load on each transformer before the reactor is added? (*b*) What is the reactance of this reactor? By what amount is the total copper loss in the transformers reduced?

158. It is desired to make a full-load heat run on a 120 hp., 220-volt, 25-cycle, single-phase motor. The efficiency and power factor for this condition are 90.2 and 94.8 per cent, respectively. The only source of supply is a 2200-volt, 25-cycle circuit. There are available four transformers, the data concerning which are given in the following table:

Number	Kilovolt-amperes	Frequency	Potential	Open circuit		Short circuit		
				Watts[1]	Volt-amperes	Volts	Amperes	Watts
A	50	25	2,200–220	598	2,960	102	22.7	676
B	100	60	2,200–220	940	3,750	68	45 4	1,020
C	100	25	1,100–110	865	4,940	48	90.8	1,140
D	200	60	4,400–440	1,840	7,480	152	45.4	1,680

[1] Ratio of eddy-current to hysteresis loss is 1: 3.

(*a*) Which transformer should be used? How does the heat loss in the transformer compare with the loss at rated full load? (*b*) If more than 100 kv.-a. is desired from the 25-cycle circuit, could any of the above transformers be operated in parallel? If so, which ones? What is the maximum kilovolt-amperes that could be delivered without overloading either? What would be the division of this load between them?

159. The following data are given on five transformers:

Number	Rating		Frequency	Short-circuit data			Core loss at rated potential[1]
	Kilovolt-amperes	Potential		*V*	*P*	*I*	
A	500	11,000:2,200	25	265	3,300	45 4	3,020
B	500	22,000:4,400	50	1,700	4,020	22.7	2,800
C	500	11,000:2,200	25	945	3,980	45 4	3,400
D	500	6,600:1,320	25	300	3,500	75.8	3,200
E	500	11,000:2,200	60	450	3,740	45.4	3,080

[1] Ratio of eddy current to hysteresis loss is 1: 3.

Which of the above transformers, operating in parallel, can be used to supply a load of 780 kv.-a. at 2200 volts from an 11,000-volt, 25-cycle circuit with the least over load on any one transformer? What kilovolt-ampere load will each carry?

Assume that the transformer rating is based on the total loss at full load and is independent of the division between core and copper losses.

160. The following data are given on four 1000 kv.-a. transformers:

Number	Rating		Core loss at rated potential[1]	Equivalent impedance	
	Potential	Frequency		*R*, per cent	*X*, per cent
A	11,000:2,300	60	3,500	0.685	10.6
B	11,000:2,300	60	3,800	0.710	4.18
C	13,200:2,500	60	3,600	0.670	6.40
D	13,200:2,760	50	3,750	0.680	6.95

[1] Ratio of eddy current loss to hysteresis loss is 1:3.

What combination of these transformers, operating in parallel, on an 11,000-volt, 60-cycle circuit will supply the greatest load at 2300-volts without overheating any one?

Assume that the safe output is determined by the total heating loss and is not affected by the division of the total loss between core loss and copper loss.

161. The following data are given on four transformers:

Number	Kilovolt-amperes	Rating		Core loss at rated potential[1]	Equivalent impedance	
		Potential	Frequency		*R*, per cent	*X*, per cent
A	100	2200:220	60	560	1.16	5.24
B	100	1100:110	25	480	1.22	1.78
C	200	1100:110	60	540	0.98	3.15
D	500	1100:110	25	440	0 86	2.16

[1] Ratio of eddy current to hysteresis loss is 1:3.

Which of these transformers can be operated in parallel on 1100-volt, 25-cycle circuit? What is the greatest load that they can supply without over heating any one?

Assume that the safe output is determined by the total heating loss and is not affected by the division of the total loss between core loss and copper loss.

162. Two similar 5-kw. lighting transformers which give a ratio of transformation of 1100:110 volts are connected in series on both the high- and low-tension sides. With both low-tension windings short circuited and with 326 volts impressed on the high-tension windings connected in series, the current is 4.55 amp. and the power supplied is 101 watts. On the low-tension side, these transformers supply power to a 3-wire system. The resistances of the lamp loads on the two sides of the neutral are 2.8 and 2.1 ohms. The high-tension line potential is 2200 volts. What is the current in the neutral conductor? What is the potential across each lamp load? If each lamp takes approximately 50 watts, how many should be turned off on one side in order that all of the lamps shall burn with the same brilliancy?

163. The transformers described in problem 162 are connected in series on both the high- and low-tension sides and are delivering power to a 3-wire circuit on each side of which there are two equal lamp loads taking 32 amp. at 110 volts.

What is the high-tension line potential? If one of these loads is short circuited, what will be the potential across the other on the assumption that its resistance and the high-tension line potential are both unchanged?

164. The transformers described in problem 162 are connected in parallel on the high-tension and in series on the low-tension sides and are delivering power to a 3-wire lighting circuit. The resistances of the lamp loads on the two sides of the system are 2.8 and 2.1 ohms. What is the current in the neutral conductor? If the neutral conductor is disconnected from the transformers, what is the potential across each lamp load?

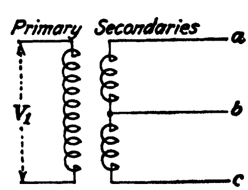


Fig. 6.

165. A 100-kv.-a. transformer has two equal secondary coils which are connected in series, as shown in Fig. 6. The ratio of transformation of the primary potential V_1 to the secondary potential V_{ac} is 2200:220. The resistance of the primary is 0.241 ohm, and the resistance of each secondary is 0.00124 ohm. If either the secondary winding *ab* or the secondary winding *bc* is short circuited and 61 volts applied to the primary, the current is 45 amp. If the

secondary winding *bc* is short circuited and 2.62 volts is applied to the secondary winding *ab*, the current is 450 amp. (*a*) If both secondaries are simultaneously short circuited, what potential must be applied to the primary in order that the current will be 45 amp.? (*b*) With 2200 volts impressed on the primary and an inductive load that has an impedance of $0.391 + j0.293$ connected across the secondary terminals *ac*, what is the secondary terminal potential?

166. The transformer described in problem 165 has connected across its secondary terminals *ab* a lamp load having a resistance of 0.25 ohm and across its secondary terminals *bc* another lamp load also having a resistance of 0.25 ohm. (*a*) If the primary potential is 2200 volts, what are each of the secondary potentials? (*b*) What is the current in the secondary neutral conductor? (*c*) If the secondary neutral conductor is broken at the transformer, what will be the potential across each of the lamp loads?

167. The transformer described in problem 165 has connected across its secondary terminals *ab* a lamp load having a resistance of 0.25 ohm and across its secondary terminals *bc* another lamp load having a resistance of 0.30 ohm. (*a*) If the primary potential is 2200 volts, what are each of the secondary potentials? (*b*) What is the current in the secondary neutral conductor? (*c*) If the secondary neutral conductor is broken at the transformer, what will be the potential across each of the lamp loads?

168. A 2300-volt generator delivers 9000 kv.-a. to a 3-phase, 30,000-volt transmission line through step-up transformers. What should be the current and potential ratings of the transformers when connected in the following manner: (*a*) primaries in Δ, secondaries in Δ; (*b*) primaries in Y, secondaries in Y; (*c*) primaries in Δ, secondaries in Y; (*d*) primaries in Y, secondaries in Δ; (*e*) primaries in V, secondaries in V; (*f*) primaries in T, secondaries in T.

169. A 6-phase synchronous converter takes 1052 kv.-a. from a 3-phase, 6600-volt circuit through step-down transformers. The 6-phase potential to neutral is 230 volts. What should be the current and potential ratings of the transformers when connected in the following manner: (*a*) primaries in Δ, secondaries in double Δ; (*b*) primaries in Δ, secondaries in diametrical; (*c*) primaries in Δ, secondaries in double Y; (*d*) What would have been the rating of the primaries if they had been connected in Y instead of in Δ?

170. Three autotransformers are used to raise the line potential of a 3-phase circuit from 2200 to 2300 volts. If the maximum power delivered is 900 kw. at 0.8 power factor, what should be the current and potential rating of each transformer winding?

171. A 66,000-volt transmission line must supply 1500 kv.-a. to a balanced 3-phase load through two groups of transformers which will, on open circuit, reduce the line potential to 460 volts. The first group is connected in Δ-Y and reduces the line potential to 6600 volts. The second group is also connected in Δ-Y and reduces the line potential to the desired value. (*a*) What must be the current and potential ratings of the primary and secondary windings of each transformer? (*b*) The short-circuit data on each transformer are

First group . . . . $V = 300, I = 131, P = 4600.$
Second group . . . $V = 550, I = 75.8, P = 4400.$

If the high-tension line potential is 66,000 volts, at what line potential will an inductive load taking 2000 amp. per terminal at a power factor of 0.90 be delivered?

172. It is desired to transform 200 kw. from 2- to 3-phase by Scott-connected transformers. The 2-phase line potential is 2200 volts, and the 3-phase line potential is 230 volts. What should be the current and potential rating and the ratio of transformation of each transformer?

173. It is desired to transform 100 kw. from 3-phase at 6600 volts to 2-phase at 110 volts by the means of Scott-connected transformers. What should be the current and potential rating and the ratio of transformation of each transformer?

174. A 30,000-volt transmission line must supply 200 kv.-a. to a balanced 4-phase load through two groups of transformers which will, on open circuit, give a 4-phase potential of 115 volts to neutral. The first group is connected in Δ-Y and reduces the line potential to 6600 volts. The second group is connected in T and reduces the line potential to the desired value. What must be the current and potential rating of each transformer?

175. Three transformers whose primaries are conncted in Y and whose secondaries are connected in Δ are in parallel on the primary side with three others whose primaries and secondaries are both connected in Y. If a secondary terminal of the first set is connected to a secondary terminal of the second set, what

are the greatest and least potentials that can exist between the other secondary terminals of the two sets? The line potentials on the secondary sides are 1100 volts for each set of transformers.

176. Three transformers whose primaries and secondaries are both connected in Δ are in parallel on the primary side with three others whose primaries are connected in Δ and whose secondaries are connected in Y. If a secondary terminal of the first set is connected to a secondary terminal of the second set, what are the greatest and least potentials that can exist between the other secondary terminals of the two sets? The line potentials on the secondary sides are 1100 volts for each set of transformers.

177. Three transformers whose primaries and secondaries are both connected in Δ are in parallel on the primary side with three others whose primaries are connected in Y and whose secondaries are connected in Δ. If a secondary terminal of the first set is connected to a secondary terminal of the second set, what are the greatest and least potentials that can exist between the other secondary terminals of the two sets? The line potentials on the secondary sides are 1100 volts for each set of transformers.

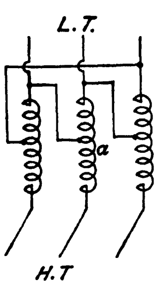


FIG. 7.

178. Three autotransformers are connected, as shown in Fig. 7, to receive power from a 3-phase, 11,000-volt circuit. The ratio of transformation for each transformer from high to low tension is 2:1. What is the secondary line potential, and what is the phase relation of the corresponding primary and secondary line potentials on open circuit?

179. Three autotransformers are connected, as shown in Fig. 8, to receive power from a 3-phase, 11,000-volt circuit. The ratio of transformation from high tension to low tension is 2:1. What is the secondary line potential, and what is the phase relation of the corresponding primary and secondary line potentials on open circuit?

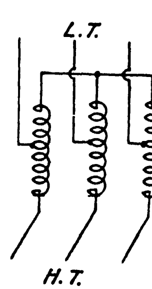


FIG. 8.

180. Three autotransformers are connected, as shown in Fig. 9, to receive power from a 3-phase, 11,000-volt circuit. The ratio of transformation for each transformer from high to low tension is 2:1. What is the secondary line potential,

and what is the phase relation of the corresponding primary and secondary line potentials on open circuit?

181. Three autotransformers are connected, as shown in Fig. 9, to give a ratio of transformation of 2:1. What are the relative magnitudes and phase relations of the low-tension current and the currents in the two windings which are interconnected at the point *a*?

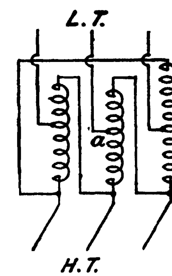


FIG. 9.

182. The three autotransformers which were used in problem 181 are reconnected as shown in Fig. 7. What are the relative magnitudes of the currents in the three windings which are interconnected at the point *a*?

183. (*a*) On the basis of the same heating loss, compare the full-load kilowatt output at unity power factor of two single-phase transformers connected in open Δ with their name-plate rating. (*b*) On the basis of the same heating loss, compare the full-load kilowatt output at 0.87 power factor—both lagging and leading—of two single-phase transformers connected in open Δ with 87 per cent of their name-plate rating. In each case, the load is balanced.

184. (*a*) Three single-phase transformers with both primaries and secondaries connected in Δ supply a balanced load of 100 kw. at unity power factor. If it is necessary to remove one of these transformers from the line, by what per cent will the copper loss in each of the other two transformers be increased? (*b*) If the load had been a balanced one taking 87 kw. at 0.87 power factor—both leading and lagging—what would have been the per cent increase in the copper loss in each of the other transformers?

185. (*a*) On the basis of the same copper loss in each transformer, compare the full-load kilowatt output at unity power factor of two equal single-phase transformers connected in T with their name-plate rating. (*b*) On the basis of the same copper loss in each transformer, compare the full-load kilowatt output at 0.87 power factor of two equal single-phase transformers connected in T with 87 per cent of their name-plate rating.

186. On the basis of the same copper loss in each transformer, compare the full-load kilowatt output of two equal single-phase transformers connected in open Δ with the full-load output of the same transformers connected in T (*a*) at unity power factor, (*b*) at 0.87 power factor—both lagging and leading.

187. Two identical banks of transformers, each connected in V, are paralleled on both their high- and low-tension sides, but with the open sides of the V's across different phases. What is the greatest output that these two banks can deliver as compared with (*a*) the output of a single bank, (*b*) the output of a single transformer? The load on the transformers is balanced.

188. Three transformers each of 100 kv.-a. capacity are connected (*a*) in Y on the high-tension side and in Δ on the low-tension side, (*b*) in Δ on both the high- and low-tension sides. These transformers have the following per cent values of equivalent resistance and equivalent reactance:

Number	R	X
1	0 92	4 52
2	0 92	4 52
3	0 96	3 14

If these transformers supply a balanced load of 300 kv.-a, what per cent of its rated kilovolt-amperes does each transformer deliver? What is the greatest balanced kilovolt-ampere load these transformers can deliver without overloading any one?

189. Two banks of Δ-Δ-connected transformers are operating in parallel. The six transformers are all of the same design and have an equivalent resistance of 0.64 per cent and an equivalent reactance of 5.72 per cent. If it becomes necessary to remove one of these transformers, what per cent of their rated kilovolt-amperes can the remaining five deliver to a balanced load without overloading any one?

190. Three banks of Δ-Δ-connected transformers are operating in parallel. The transformers are all of the same design and have an equivalent resistance of 0.58 per cent and an equivalent reactance of 7.84 per cent. At a time when these transformers are delivering their rated kilovolt-amperes to a balanced load, it becomes necessary to remove one transformer. What per cent of its rated kilovolt-amperes does each transformer now deliver? What is the greatest balanced kilovolt-ampere load that the eight transformers can deliver without overloading any one?

191. Three single-phase transformers are connected in Δ on both the primary and secondary sides. With a primary potential of 22,000 volts, the secondary potential on open circuit is 440

volts. The short-circuit characteristic data of each transformer are: $V = 1020$ volts, $I = 1.136$ amp., $P = 351$ watts. If the secondary-terminal potential is 440 volts when there is a single-phase load taking 40 kw. at 0.8 power factor connected across one phase of the secondary, what will be the per cent rise in this potential when the load is thrown off?

192. (*a*) Compare the regulation of three 100-kv.-a. transformers whose primaries and secondaries are connected in Δ with that of two 100-kv.-a. transformers whose primaries and secondaries are connected in open Δ when a single-phase load of 100 kw. at 0.8 power factor is delivered on the secondary side. The secondary or low-tension potential under load conditions is 2200 volts, and the ratio of transformation is 5:1. The short-circuit data on each transformer are $V = 310$ volts, $I = 9.1$ amp. (full load), $P = 1000$ watts. In the case of the open Δ, the load is connected across one transformer. (*b*) Compare the regulation in the two cases when a single-phase load of 150 kw. at 0.8 power factor is supplied. In the case of the open Δ, the load is connected across the terminals of the two transformers, *i.e.*, across the open side.

193. Two banks of transformers are arranged, as shown in Fig. 10 to transform 200 kv.-a. from 3-phase at 30,000 volts to 4-

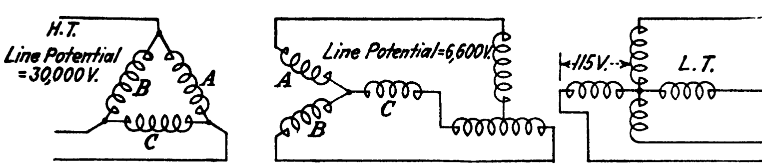


FIG. 10.

phase at 115 volts. The first bank reduces the line potential from 30,000 to 6600 volts. The second bank reduces the potential to 115 volts to neutral. (*a*) What should be the current and potential rating of each transformer? (*b*) If transformer A is damaged so that it is necessary to disconnect it from the high-tension line and short circuit its low-tension winding, how will the magnitude and phase of the 4-phase potentials to neutral be affected? (*c*) If transformer B is damaged so that it is necessary to disconnect it from the high-tension line and short circuit its low-tension winding, how will the magnitude and phase of the 4-phase potentials to neutral be affected? (*d*) If either trans-

former A or B must be removed from the circuit, what reconnection of transformer C can be made so as to restore the balance of the 4-phase potentials? If this is done, what will be the 4-phase potential to neutral?

194. Two 100-kv.-a., 11,000:2200-volt transformers are connected in V to a balanced 3-phase, 11,000-volt circuit. The short-circuit data on each transformer are $V = 660$, $I = 9.1$, $P = 1000$. If a single-phase capacitive load taking 50 amp. at 0.60 power factor is connected across one secondary, what is the potential across the open side of the V on the secondary?

Assume that, on the high-tension side, the potential across the open side of the V leads that across the loaded transformer by 120 deg.

195. Three identical 500-kv.-a., 11,000:2300-volt transformers are connected in Δ on both their high- and low-tension sides.

The open- and short-circuit data are:

Open circuit...........	$V = 2300$,	$I = 3.4$,	$P = 2960$
Short circuit...........	$V = 345$,	$I = 45.5$,	$P = 3375$

(*a*) What is the greatest single-phase load that the transformers can supply without overloading any one? (*b*) A single-phase inductive load taking 70 amp. at 0.80 power factor is connected to the high-tension side of one of the transformers. If the primary potentials are each 2300 volts, what is the potential of each of the high-tension windings? What is the efficiency of the transformers at this load?

196. Four identical single-phase transformers are connected in mesh on both their high- and low-tension sides. The transformers are each rated at 100 kv.-a., 11,000:2200 volts, and have equivalent resistances and reactances of 0.64 and 4.56 per cent, respectively. (*a*) What is the greatest single-phase load that can be supplied from adjacent line terminals? (*b*) What is the greatest single-phase load that can be supplied from diametrical line terminals? (c) If the high-tension potentials between adjacent terminals are 11,000 volts and in quadrature, that will be the potential of each low-tension winding when a single-phase inductive load of 125 kv.-a. at 0.8 power factor is connected to adjacent secondary terminals?

197. Three identical single-phase transformers are connected in Y on the high-tension side and in Δ on the low-tension side, except that at one corner the Δ is open and a voltmeter is inserted.

The high-tension potential is 11,000 volts, and the transformers have a ratio of transformation of $5:\sqrt{3}$. An oscillogram of the potential of one of the high-tension windings shows it to consist principally of a fundamental and a 35 per cent third harmonic. What does the voltmeter read that is inserted in the Δ?

198. Two identical, 100-kv.-a., single-phase transformers, each having one primary P and two equal secondaries S_1 and S_2, have the following short-circuit data:

P-S_1............. Potential = 546, current = 9.1, power = 782
P-S_2............. Potential = 546, current = 9.1, power = 782
P-S_1 and S_2 in
parallel........ Potential = 435, current = 9.1, power = 587

The primaries are connected to a balanced 2-phase, 11,000-volt circuit. (*a*) When the secondaries are arranged to supply power to a 4-phase, 5-wire circuit, what is the greatest single-phase load that can be supplied (1) from adjacent terminals, (2) from diametrical terminals? (*b*) If this load is inductive and at 0.80 power factor, by what per cent will each of the secondary line potentials be affected by its application (1) across adjacent terminals, (2) across diametrical terminals?

199. Two identical, 100-kv.-a., single-phase transformers, each having one primary P and two equal secondaries S_1 and S_2, have the following short-circuit data:

P-S_1............. Potential = 546, current = 9.1, power = 782
P-S_2............. Potential = 546, current = 9.1, power = 782
P-S_1 and S_2 in
parallel......... Potential = 435, current = 9.1, power = 587

The primaries are connected to a balanced 2-phase, 11,000-volt circuit. (*a*) When the secondaries are mesh connected and supply power to a 4-phase circuit, what is the greatest single-phase load that can be supplied (1) from adjacent terminals, (2) from diametrical terminals? (*b*) If this load is inductive and at 0.80 power factor, by what per cent will each of the secondary line potentials be affected by its application (1) across adjacent terminals, (2) across diametrical terminals?

200. A 3-phase, 60-cycle alternating-current generator supplies power to a transmission line through step-up transformers whose low-tension windings are connected in Y and whose high-tension windings are connected in Δ. These transformers are rated at

3333 kv.-a. and have a ratio of transformation of 3800:80,000 volts. With the high-tension winding short circuited and with 162 volts at 60 cycles impressed on the low-tension winding, full-load current exists in each winding and 18.85 kw. is supplied. The neutral points of both the generator and the low-tension windings of the transformers are connected to the same ground bus. When the transformers are delivering no load on the high-tension side and the excitation of the generator is adjusted so that its terminal potential is 6600 volts, the potential from line to neutral is found to be 3850 volts. A third harmonic in the phase potential is suspected, and the oscillograph shows that one with a magnitude of 14 per cent of the fundamental does exist.

What is the copper loss in each transformer when there is no load delivered to the high-tension line. Compare this with the full-load copper loss that would be produced in the transformers if their neutral point were not grounded.

201. A 1000-kw., 6-phase, 25-cycle, 600-volt synchronous converter is supplied with power from a 3-phase, 13,200-volt transmission line. The high-tension windings of the transformers are connected in Δ, and the low-tension windings are connected to diametrical points of the armature of the converter. With the low-tension winding of a transformer short circuited and with 345 volts at 25 cycles impressed on the high-tension winding, full-load current, or 25.2 amp., flows in the winding, and 3070 watts is supplied. At a time that the transformers receive 1120 kw. and the line potential and current are 13,200 volts and 49.8 amp., oscillographic records show that the potential across diametrical points of the armature of the converter practically consists of a fundamental and a third harmonic that is 8.5 per cent of and in phase with the fundamental.

Calculate the total copper loss in each transformer. If the low-tension windings had been divided and connected in double Y with no connection between their neutral points, what would have been the copper loss in each transformer under the same load condition? What will be the effect on the transformer core losses of making this change in the connection of the low-tension windings?

202. A 3000-kw., 5000-volt, 60-cycle alternating-current generator supplies power to a 3-phase transmission line through three 1000-kv.-a. transformers which are connected in Y on the low-tension and in Δ on the high-tension sides. With the low-tension

winding of one transformer short circuited and with 3240 volts at 60 cycles impressed on the high-tension side, full-load current flows in the windings and 7490 watts is supplied. The ratio of transformation is 2890:66,000 volts. Both the neutral point of the armature winding and the neutral point of the low-tension windings of the transformers are directly connected to the same bus. When the transformers are delivering 2650 kw. at 0.875 power factor and a line potential of 66,000 volts, they become unduly hot. Oscillographic records show that, at this time, the terminal potential of each phase of the generator practically consists of a fundamental and a third harmonic which is 12 per cent of and in phase with the fundamental.

What is the copper loss in each transformer? If the neutral point of the transformer windings is disconnected from the ground bus, what will be the copper loss in each transformer for the same load condition? What will be the effect on the transformer core loss of making this change in the connections?

MAGNETIC DATA

Mean *BH* Curve

Abscissæ (*H*), gilberts per centimeter	Ordinates (*B*), kilogausses			
	Sample A, 17 mil	Sample B, 14 mil	Sample C, 14 mil	Sample D, 14 mil
2 0	10.0	8.0	8 0	9.0
4.0	12 0	10.6	11.3	11.4
6 0	12.85	11.6	12.2	12.2
8.0	13.45	12.3	12.8	12.8
10.0	14.0	13.0	13.3	13.2
15.0	14.8	13.9	13.9	13.8
20.0	15.4	14.5	14.3	14.2
30.0	16.2	15.3	14.8	14.8
50.0	17.0	16.2	15.6	15.6
100.0	18.0	17.2	16.9	17.0
150.0	18.5	17.8	17.6	18.0

MAGNETIC DATA

Core-loss Curve

Abscissæ (B), kilogausses	Ordinates (core loss), watts per pound							
	Sample A		Sample B		Sample C		Sample D	
	25~	60~	25~	60~	25~	60~	25~	60~
6.0	0.220	0.575	0.150	0.350	0.100	0.285	0.125	0.345
8.0	0.355	0.975	0.250	0.600	0.210	0.520	0.203	0.560
10.0	0.525	1.475	0.380	0.940	0.325	0.795	0.310	0.825
11.0	0.610	1.750	0.455	1.125	0.375	0.943	0.383	1.020
12.0	0.710	2.075	0.540	1.310	0.460	1.100	0.470	1.230
13.0	0.825	.....	0.650	1.520	0.550	1.275	0.565	1.480
14.0	0.950	.....	0.775	1.750	0.685	1.475	0.670	1.760
15.0	1.100	.....	0.925	.....	0.840	.....	0.790	2.070

HYSTERESIS CURVES[1]

Curve 1, maximum density = 10,000 gausses		Curve 2, maximum density = 15,000 gausses	
B	*H*	*B*	*H*
−10,000	−3.75	−15,000	−12.0
− 9,200	−1.50	−14,500	− 7.20
− 7,700	0.00	−13,500	− 4.00
− 5,000	+1.40	−11,800	− 1.50
− 2,500	+2.10	−10,300	0.00
0	+2.35	− 8,000	+ 1.50
+ 4,500	+2.50	− 4,600	+ 2.50
+ 7,500	+2.95	− 2,500	+ 2 80
+10,000	+3.75	0	+ 3.00
....	......	+ 5,000	+ 3.25
....	......	+ 7,500	+ 3 75
....	......	+10,000	+ 4 65
....	......	+12,500	+ 6 30
....	......	+13,900	+ 8.00
....	......	+14,600	+ 9.50
....	......	+15,000	+12.00

Weight of iron in core in pounds equals gross volume in cubic inches multiplied by 0.9 × 0.272.

[1] One side only of the curve is given, from the negative maximum to the positive maximum density.

TRANSFORMER DATA

Number	Kilovolt-amperes	Type	Cycles	Potential		Open circuit		Short circuit		
				High tension	Low tension	Watts	Volt-amperes	Volts	Amperes	Watts
L	100	core	60	11,500	230	560	3,600	228	8.7	1,162
M	500	core	60	13,200	2,500	2,190	17,500	600	37.9	4,320
N	1,000	shell	60	11,000	2,300	3,500	28,000	480	90.8	6,880
O	3,333	core	60	107,250	2,300	11,910	88,600	202	1,448	20,660
P	3,333	core	60	95,000	24,200	18,800	161,000	1,000	138	18,470
Q	4,500	core	60	24,730	11,000	10,400	81,000	840	409	26,570
R	5,000	shell	60	69,200	19,020	14,000	120,000	5,410	75.7	30,400
S	5,000	core	60	110,000	12,000	12,450	64,500	1,510	417	35,500
T	6,667	3-phase core	60	100,000Y	6,600Y	23,800	155,000	646Y	585	43,000
U	25,000	3-phase core	60	120,000Y	14,000Y	67,000	400,000	9,465Y	120	137,900

AUTOTRANSFORMER DATA

Number	Kilovolt-amperes	Type	Cycles	Potential		Open circuit		Short circuit		
				High tension	Low tension	Watts	Volt-amperes	Volts	Amperes	Watts
G	31.4	core	60	7,850	4,760	105	360	88	4.0	281
H	12,500	shell	60	15,960	7,980	21,900	90,000	930	783	57,500
I	15,000	3-phase core	60	110,000Y	72,000Y	45,700	263,000	5,300	41.5	66,550

TYPICAL RATIO OF MAXIMUM VALUE OF EXCITING CURRENT TO ITS R.M.S. VALUE, WHEN TIME VARIATION OF CORE FLUX IS SINUSOIDAL

Maximum flux density, gausses	$\frac{I_{max}}{I_{r.m.s.}}$
10,000	1 7
12,000	1 85
13,000	1 99
14,000	2 22

CHAPTER II

GENERATOR

1. The armature of a single-phase generator has 10 slots per pole with 2 coil sides per slot. The breadth of the armature winding is 0.8. Show the arrangement of the coil sides if the coil pitch is (*a*) unity, (*b*) 0.8.

2. The armature of a 2-phase generator has 12 slots per pole with 2 coil sides per slot. The breadth of each phase of the armature winding is 0.5. Show the arrangement of the coil sides if the coil pitch is (*a*) unity, (*b*) 10 slots.

3. The armature of a 3-phase generator has 12 slots per pole with 2 coil sides per slot. The breadth of each phase of the armature winding is one-third. Show the arrangement of the coil sides if the coil pitch is (*a*) unity, (*b*) five-sixths.

4. The armature of a 3-phase generator has 15 slots per pole with 2 coil sides per slot. The breadth of each phase of the armature winding is two-thirds. Show the arrangement of the coil sides if the coil pitch is (*a*) unity, (*b*) four-fifths.

5. The armature of a 2-phase generator has 7 slots per pole with 2 coil sides per slot. There are 7 coils per pole and the phases are symmetrically arranged. Show the arrangement of the coil sides if the coil pitch is (*a*) unity, (*b*) 6 slots.

6. The armature of a 3-phase generator has 21 slots per pair of poles with 2 coil sides per slot. There are 21 coils per pair of poles, and the phases are symmetrically arranged. Show the arrangement of the coil sides (*a*) if there is one phase belt per pole and the coil pitch is 9 slots, (*b*) if there is one phase belt per pair of poles and the coil pitch is 8 slots.

7. The armature of a 3-phase, 4-pole generator has 27 slots with 2 coil sides per slot. There are 27 coils, and the phases are symmetrically arranged. Show the arrangement of the coil sides (*a*) if there is 1 phase belt per pole and the coil pitch is 6 slots, (*b*) if there is 1 phase belt per pair of poles and the coil pitch is 6 slots.

8. With normal excitation, the resultant air-gap flux in a 60-cycle alternator is 10^6 lines per pole. The flux density is

constant under the pole face and zero between the poles. (*a*) If the ratio of pole arc to pole pitch is 0.75 and the coil pitch is 1.0, what is the armature e.m.f. per turn? What is the form factor of this e.m.f.? Sketch the graphs of the flux density and the e.m.f. (*b*) If the ratio of pole arc to pole pitch is 0.75 and the coil pitch 0.67, what is the armature e.m.f. per turn? What is the form factor of this e.m.f.? Sketch the graphs of the flux density and the e.m.f. (*c*) If the ratio of pole arc to pole pitch is 0.5 and the coil pitch is 1.0, what is the armature e.m.f. per turn? What is the form factor of this e.m.f.? Sketch the graphs of the flux density and the e.m.f.

9. With normal excitation, the resultant air-gap flux in a 60-cycle alternator is 10^6 lines per pole. The flux density is constant under the pole face and decreases uniformly to zero at points midway between the poles. (*a*) If the ratio of pole arc to pole pitch is 0.75 and the coil pitch is 1.0, what is the armature e.m.f. per turn? What is the form factor of this e.m.f.? Sketch the graphs of the flux density and the e.m.f. (*b*) If the ratio of pole arc to pole pitch is 0.75 and the coil pitch is 0.67, what is the armature e.m.f. per turn? What is the form factor of this e.m.f.? Sketch the graphs of the flux density and the e.m.f. (*c*) If the ratio of pole arc to pole pitch is 0.5 and the coil pitch is 1.0, what is the armature e.m.f. per turn? What is the form factor of this e.m.f.? Sketch the graphs of the flux density and the e.m.f.

10. With normal excitation, the resultant air-gap flux in a 60-cycle alternator is 10^6 lines per pole. This flux is sinusoidally distributed along the air gap. (*a*) If the coil pitch is 1.0, what is the armature e.m.f. per turn? What is the form factor of this e.m.f.? (*b*) If the coil pitch is 0.8, what is the armature e.m.f. per turn? What is the form factor of this e.m.f.? (*c*) If the coil pitch is 0.67, what is the armature e.m.f. per turn? What is the form factor of this e.m.f.?

11. With normal excitation, the resultant air-gap flux in a 60-cycle alternator is 10^6 lines per pole. The equation of the flux density in the air gap is

$$B = B_1 \sin x + B_3 \sin 3x$$

x is the electrical angle measured from the point midway between the poles. Take $B_3 = 0.3B_1$. (*a*) If the coil pitch is 1.0, what is the armature e.m.f. per turn? What is the form factor of

this e.m.f.? (*b*) If the coil pitch is 0.8, what is the armature e.m.f. per turn? What is the form factor of this e.m.f.? (*c*) If the coil pitch is 0.67, what is the armature e.m.f. per turn? What is the form factor of this e.m.f.?

12. With normal excitation, the resultant air-gap flux in a 60-cycle alternator is 10^6 lines per pole. The equation of the flux density in the air gap is

$$B = B_1 \sin x + B_3 \sin \left(3x + \frac{\pi}{2}\right).$$

x is the electrical angle measured from the point midway between the poles. Take $B_3 = 0.3B_1$. (*a*) If the coil pitch is 1.0, what is the armature e.m.f. per turn? What is the form factor of this e.m.f.? (*b*) If the coil pitch is 0.8, what is the armature e.m.f. per turn? What is the form factor of this e.m.f.? (*c*) If the coil pitch is 0.67, what is the armature e.m.f. per turn? What is the form factor of this e.m.f.?

13. With normal excitation, the resultant air-gap flux in a 60-cycle alternator is 10^6 lines per pole. The equation of the flux density in the air gap is

$$B = B_1 \sin x + B_3 \sin (3x + \pi)$$

x is the electrical angle measured from the point midway between the poles. Take $B_3 = 0.3B_1$. (*a*) If the coil pitch is 1.0, what is the armature e.m.f. per turn? What is the form factor of this e.m.f.? (*b*) If the coil pitch is 0.8, what is the armature e.m.f. per turn? What is the form factor of this e.m.f.? (*c*) If the coil pitch is 0.67, what is the armature e.m.f. per turn? What is the form factor of this e.m.f.?

14. With normal excitation, the resultant air-gap flux in a 60-cycle alternator is 10^6 lines per pole. The equation of the flux density in the air gap is

$$B = B_1 \sin x + B_5 \sin 5x$$

x is the electrical angle measured from the point midway between the poles. Take $B_5 = 0.2\mathrm{B}_1$. (*a*) If the coil pitch is 1.0, what is the armature e.m.f. per turn? What is the form factor of this e.m.f.? (*b*) If the coil pitch is 0.8, what is the armature e.m.f. per turn? What is the form factor of this e.m.f.? (*c*) If the coil pitch is 0.67, what is the armature e.m.f. per turn? What is the form factor of this e.m.f.?

15. With normal excitation, the resultant air-gap flux in a 60-cycle alternator is 10^6 lines per pole. The equation of the flux density in the air gap is

$$B = B_1 \sin x - B_5 \sin 5x$$

x is the electrical angle measured from the point midway between the poles. (*a*) If the coil pitch is 1.0, what is the armature e.m.f. per turn? What is the form factor of this e.m.f.? (*b*) If the coil pitch is 0.8, what is the armature e.m.f. per turn? What is the form factor of this e.m.f.? (*c*) If the coil pitch is 0.67, what is the armature e.m.f. per turn? What is the form factor of this e.m.f.?

16. With normal excitation, the resultant air-gap flux in a 60-cycle alternator is 10^6 lines per pole. The flux density is constant under the pole face and zero between the poles. The armature has 8 equally spaced slots per pole. The ratio of pole arc to pole pitch is 0.67, and the coil pitch is 1.0. (*a*) If the armature winding consists of 2 inductors in series per pole placed in adjacent slots, what is the armature e.m.f. per pole? What is the form factor of this e.m.f.? Sketch the graphs of the flux density and the e.m.f. (*b*) Compare this e.m.f. and form factor with what they would have been had the winding been concentrated—*i.e.*, with two inductors in series per pole, placed in the same slot.

17. (*a*) In problem 16, if the armature winding consists of 4 inductors in series per pole placed in adjacent slots, what is the armature e.m.f. per pole? What is the form factor of this e.m.f.? Sketch the graphs of the flux density and the e.m.f. (*b*) Compare this e.m.f. and form factor with what they would have been had the winding been concentrated—*i.e.*, with 4 inductors in series per pole placed in the same slot.

18. (*a*) In problem 16, if the armature winding consists of 4 inductors in series per pole placed in alternate slots, what is the armature e.m.f. per pole? What is the form factor of this e.m.f.? Sketch the graphs of the flux density and the e.m.f. (*b*) Compare this e.m.f. and form factor with what they would have been had the winding been concentrated—*i.e.*, with 4 inductors in series per pole placed in the same slot.

19. With normal excitation, the resultant air-gap flux in a 60-cycle alternator is 10^6 lines per pole. The flux density is constant under the pole face and decreases uniformly to zero at points midway between the poles. The armature has 8 equally spaced

slots per pole. The ratio of pole arc to pole pitch is 0.67, and the coil pitch is 1.0. If the armature winding consists of 2 inductors in series per pole placed in adjacent slots, what is the armature e.m.f. per pole? What is the form factor of this e.m.f.? Sketch the graphs of the flux density and the e.m.f.

20. With normal excitation, the resultant air-gap flux in a 60-cycle alternator is 10^6 lines per pole and is sinusoidally distributed along the air gap. The armature has 12 equally spaced slots per pole. The coil pitch is 1.0. (*a*) If the armature winding consists of 6 inductors in series per pole placed in alternate slots, what is the armature e.m.f. per pole? What is the form factor of this e.m.f.? (*b*) Compare this e.m.f. with what it would have been had the 6 inductors per pole been concentrated in 1 slot.

21. (*a*) In problem 20, if the armature winding consists of 12 inductors in series per pole, one in each slot, what is the armature e.m.f. per pole? What is the form factor of this e.m.f.? (*b*) Compare this e.m.f. with what it would have been had the 12 inductors per pole been concentrated in 1 slot.

22. (*a*) In problem 20, if the armature winding consists of 8 inductors in series per pole placed in adjacent slots, what is the armature e.m.f. per pole? What is the form factor of this e.m.f.? (*b*) Compare this e.m.f. with what it would have been had the 8 inductors per pole been concentrated in 1 slot.

23. With normal excitation, the resultant air-gap flux in a 60-cycle alternator is 10^6 lines per pole. The equation of the flux density in the air gap is

$$B = B_1 \sin x + B_3 \sin 3x$$

x is the electrical angle measured from a point midway between the poles. Take $B_3 = 0.3B_1$. (*a*) If the armature winding consists of 3 equally spaced inductors per pole connected so as to give a winding which has a breadth of one-third the pole pitch and a coil pitch of 1.0, what is the armature e.m.f. per pole? What is the form factor of this e.m.f.? (*b*) Compare this e.m.f. and form factor with what they would have been had the winding been concentrated in 1 slot per pole.

24. The air-gap flux in a 3-phase, 60-cycle alternator is sinusoidally distributed. There are 15 slots per pole, and the coil pitch is 1.0. If the coil pitch is reduced to four-fifths, what is the necessary increase in the maximum flux density in the air gap to maintain the same terminal potential?

25. A 3-phase, Y-connected, 60-cycle alternator has 15 slots per pole. The coil pitch is 12 slots. The equation of the flux density in the air gap is

$$B = B_1 \sin x + B_3 \sin 3x$$

where $B_3 = 0.3B_1$.
What is the ratio of the terminal potential to the phase potential?

26. A 3-phase, Y-connected, 60-cycle alternator has 18 slots per pole. The coil pitch is 15 slots. The equation of the flux density in the air gap is

$$B = B_1 \sin x + B_3 \sin 3x$$

where $B_3 = 0.3B_1$. If the coil pitch is increased to 18 slots, what is the necessary change in the flux per pole (*a*) to maintain the same r.m.s. potential between the line terminals? (*b*) to maintain the same r.m.s. phase potential?

27. A 3-phase, Y-connected, 6600-volt, 60-cycle alternator has 360 slots with 2 series conductors per slot. The coil pitch is 10 slots. There are 30 poles. The diameter of the armature core at the air gap is 148 in., and its effective length parallel to the shaft is 17.5 in. If the air-gap flux is assumed to be sinusoidally distributed, what is its maximum density at no load and with normal excitation?

28. A 3-phase, Y-connected, 6600-volt, 60-cycle alternator has 360 slots with 2 series conductors per slot. The coil pitch is 10 slots. There are 30 poles. The diameter of the armature core at the air gap is 148 in., and its effective length parallel to the shaft is 17.5 in. (*a*) If the equation of the flux density in the air gap is

$$B = B_1 \sin x + B_3 \sin 3x$$

where $B_3 = 0.3B_1$, what is the maximum flux density in the air gap at no load and with normal excitation? (*b*) If the equation of the flux density in the air gap is

$$B = B_1 \sin x - B_3 \sin 3x$$

where $B_3 = 0.3B_1$, what is the maximum flux density in the air gap at no load and with normal excitation?

29. A 3-phase, Y-connected, 6600-volt, 60-cycle alternator has 360 slots with 2 series conductors per slot. The coil pitch

is 10 slots. The equation of the flux density in the air gap is

$$B = B_1 \sin x + B_3 \sin 3x + B_5 \sin 5x$$

where $B_3 = 0.25B_1$ and $B_5 = 0.10B_1$.
At no load and with normal excitation, what is the flux per pole?

30. The armature coils of an alternator may be connected either 3-phase, Y, or 2-phase. There are 12 slots per pole, the coil pitch is 10 slots, and the equation of the air-gap flux density is

$$B = B_1 \sin x + B_3 \sin 3x$$

where $B_3 = 0.20B_1$.
What is the ratio of the 3-phase line potential to the 2-phase potential?

31. The armature coils of an alternator may be connected 3-phase, Y, or 2-phase. There are 12 slots per pole. The coil pitch is 10 slots. When the coils are connected 2-phase, the equation of the armature e.m.f. is

$$e = E_1 \sin \omega t + E_3 \sin 3\omega t + E_5 \sin 5\omega t$$

where $E_3 = 0.10E_1$ and $E_5 = 0.15E_1$.
If the armature coils are reconnected 3-phase, Y, (*a*) what will be the equation of the phase e.m.f. and (*b*) what will be the equation of the e.m.f. between the line terminals?

32. The armature coils of an alternator may be connected 3-phase, Y, or 2-phase. There are 12 slots per pole. The coil pitch is 10 slots. When the coils are connected 3-phase, the equation of the armature phase e.m.f. is

$$e = E_1 \sin \omega t + E_3 \sin 3\omega t + E_5 \sin 5\omega t$$

where $E_3 = 0.10E_1$ and $E_5 = 0.15E_1$.
If the armature coils are reconnected 2-phase, what will be the equation of the armature e.m.f.?

33. The armature coils of an 8-pole alternator may be connected 3-phase, Y, or 2-phase. There are 12 slots per pole with 2 coil sides per slot. Each coil has 2 turns and a pitch of 10 slots. The equation of the e.m.f. generated in a single coil having 10 turns and a pitch of 12 slots is

$$e = E_1 \sin \omega t + E_3 \sin 3\omega t + E_5 \sin 5\omega t$$

where $E_3 = 0.20E_1$ and $E_5 = 0.10E_1$. (*a*) When the armature coils are connected 3-phase, Y, what is the equation of the

phase e.m.f.? (*b*) When the armature coils are connected 3-phase, Y, what is the equation of the e.m.f. between the line terminals? (*c*) When the armature coils are connected 2-phase. what is the equation of phase e.m.f.?

34. A single-phase turboalternator is rated to deliver 1000 kv.-a. at 5200 volts when driven at 1500 r.p.m. The armature has 48 slots, 8 of which, or 2 per pole, carry no inductors, so that the breadth of the winding is 0.83. In each of the other 40 slots there are 4 inductors in series. The coil pitch is 1.0. What is the no-load terminal potential when the air-gap flux is 40 megalines per pole and the speed is 1510 r.p.m.?

35. A single-phase alternator is rated to deliver 250 kv.-a. at 2200 volts when driven at 375 r.p.m. The field structure has 24 poles; and the armature, 240 slots uniformly spaced. The breadth of the armature winding is 0.6, and all of the inductors are connected in series. The coil pitch is 1.0. In any belt, each of the 4 central slots contains 3 inductors, while each of the outer slots contains 2 inductors. What is the no-load terminal potential when the air-gap flux is 3.9 megalines per pole and the speed is 370 r.p.m.?

36. A 2-phase water-turbine-driven generator is rated to deliver 900 kv.-a. at 5000 volts. The field structure has 46 poles, and the armature has 2 slots per pole per phase. There are 11 inductors in series per slot. The coil pitch is 1.0. What is the no-load terminal potential when the air-gap flux is 5.4 megalines per pole and the generator is driven at its normal speed of 120 r.p.m.?

37. A 2-phase, 60-cycle, engine-driven alternator is rated to deliver 3500 kv.-a. at 11,500 volts. The armature has 576 slots with 5 inductors in series per slot. The coil pitch is 1.0. The field structure has 96 poles. What is the armature e.m.f. when the resultant air-gap flux is 6.3 megalines per pole and the speed is 74 r.p.m?

38. The armature of a 3-phase, 50-cycle, 12-pole alternator has 54 slots with 2 inductors per slot. The inductors are arranged symmetrically in the following order, which repeats itself for every pair of poles, *i.e.* for every 9 slots: In the first, third, fourth, sixth, seventh, and ninth slots, both inductors are in phases 1, 3, 2, 1, 3, and 2, respectively. In the second, fifth, and eighth slots, the top inductors are in phases 3, 1, and 2, respectively, and the bottom inductors are in phases 1, 2, and

3, respectively. The inductors in each phase are connected in series, and the phases are connected in Y. (*a*) If the resultant no-load air-gap flux is sinusoidally distributed and has a value of 8×10^5 lines per pole, what is the terminal potential? (*b*) What are the pitch and breadth factors for the fifth and seventh harmonics in the phase e.m.f.?

39. The armature core of a 3-phase alternator has 12 slots per pole. Each slot contains 2 coil sides, and each coil has 4 turns. The coil pitch is 10 slots. What are the pitch and breadth factors for the fundamental and the third, fifth, and seventh harmonics in the phase e.m.f.?

40. Compute the pitch and breadth factors for the fundamental, third, and fifth harmonics in the phase e.m.f. of the armature windings described in (*a*) problem 1, (*b*) problem 2, (*c*) problem 3, (*d*) problem 4, (*e*) problem 5, (*f*) problem 6, (*g*) problem 7.

41. The armature core of a 3-phase, 2-pole alternator has 21 slots. The armature coils have a pitch of 9 slots, and they are connected to give symmetrical phase e.m.fs. (*a*) What are the pitch and breadth factors for the fundamental component of the e.m.f.? (*b*) What are the pitch and breadth factors for the fifth-harmonic component of the e.m.f.?

42. The armature core of a 3-phase, 4-pole alternator has 39 slots. The armature coils have a pitch of 8 slots, and they are connected to give symmetrical phase e.m.fs. What are the pitch and breadth factors (*a*) for the fundamental component of the e.m.f., (*b*) for the fifth-harmonic component of the e.m.f.?

43. A 3-phase, Y-connected, 25-cycle alternator is rated to deliver 7500 kv.-a. at a terminal potential of 12,000 volts. The field structure has 12 poles, and the armature has 180 slots. There are 4 series inductors per slot. The coil pitch is 12 slots. What is the no-load terminal potential when the air-gap flux of 52 megalines per pole is sinusoidally distributed?

44. If the air-gap flux is sinusoidally distributed and has a maximum density of 7700 gausses, what is the armature e.m.f. in alternator *A*, *B*, *C*, *D*, *E*, *F*, *G*, or *H*?

45. A 2-phase alternator has 6 slots per pole with 2 coil sides per slot. There are 2 turns per coil, and the coil pitch is 6 slots. The pole pitch is *P* in., the length of the armature core parallel to the shaft is *L* in., and the effective length of the air gap is *g* in. The armature currents are *I* amp. per phase and are balanced. Assume that each coil produces a component distribution of

m.m.f. that is rectangular. Plot the distribution of m.m.f. along the air gap due to the armature currents at a time when the current in one phase is zero; also, when the current in this phase is 0.707 of its maximum value. What is the maximum flux density in the air gap at each of these moments? What is the flux per pole at each of these moments?

46. A 2-phase alternator has 6 slots per pole with 2 coil sides per slot. There are 2 turns per coil, and the coil pitch is 5 slots. The pole pitch is P in., the length of the armature core parallel to the shaft is L in., and the effective length of the air gap is g in. The armature currents are I amp. per phase and are balanced. Assume that each coil produces a component distribution of m.m.f. that is rectangular. Plot the distribution of m.m.f. along the air gap due to the armature currents at a time when the current in one phase is zero; also, when the current in this phase is 0.707 of its maximum value. What is the maximum flux density in the air gap at each of these moments? What is the flux per pole at each of these moments?

47. A 3-phase, Y-connected alternator has 6 slots per pole with 2 coil sides per slot. There are 2 turns per coil, and the coil pitch is 6 slots. The pole pitch is P in., the length of the armature core parallel to the shaft is L in., and the effective length of the air gap is g in. The armature currents are I amp. per phase. Plot the distribution of m.m.f. along the air gap due to the armature currents at a time when the current in one phase is zero; also, when the current in this phase has its maximum value. What is the maximum flux density in the air gap at each of these moments? What is the flux per pole at each of these moments?

48. A 3-phase, Y-connected alternator has 6 slots per pole with 2 coil sides per slot. There are 2 turns per coil, and the coil pitch is 5 slots. The pole pitch is P in., the length of the armature core parallel to the shaft is L in., and the effective length of the air gap is g in. The armature currents are I amp. per phase. Plot the distribution of m.m.f. along the air gap due to the armature currents at a time when the current in one phase is zero; also, when the current in this phase has its maximum value. What is the maximum flux density in the air gap at each of these moments? What is the flux per pole at each of these moments?

49. The stator of an alternator has 12 slots per pole with 2 coil sides per slot. Each coil has 4 turns and a pitch of 12 slots. The pole pitch is 15 in., and the length of the armature core parallel

to the shaft is 18 in. The effective length of the air gap is 0.5 in. The phase currents are balanced, and are each 100 amp. Assume that the distribution of m.m.f. due to a single armature coil is rectangular. (*a*) The armature coils are connected to give a 2-phase winding. Plot the distribution of armature m.m.f. along the air gap at each of 6 equally spaced intervals of the time during the half-cycle. What is the maximum flux density in the air gap at each of these moments? What is the flux per pole due to the armature currents at each of these moments? (*b*) The armature coils are connected to give a 3-phase winding. Plot the distribution of armature m.m.f. along the air gap at each of six equally spaced intervals of time during the half-cycle. What is the maximum flux density in the air gap at each of these moments? What is the flux per pole due to the armature currents at each of these moments?

50. The stator of an alternator has 12 slots per pole with 2 coil sides per slot. Each coil has 4 turns and a pitch of 10 slots. The pole pitch is 15 in., and the length of the armature core parallel to the shaft is 18 in. The phase currents are balanced and are each 100 amp. Assume that the distribution of m.m.f. due to a single armature coil is rectangular. (*a*) The armature coils are connected to give a 2-phase winding. Plot the dsitribution of armature m.m.f. along the air gap at each of six equally spaced intervals of time during the half cycle. What is the maximum flux density in the air gap at each of these moments? What is the flux per pole due to the armature currents at each of these moments? (*b*) The armature coils are connected to give a 3-phase winding. Plot the distribution of armature m.m.f. along the air gap at each of six equally spaced intervals of time during the half-cycle. What is the maximum flux density in the air gap at each of these moments? What is the flux per pole due to the armature currents at each of these moments?

51. The stator of an alternator has 12 slots per pole with 2 coil sides per slot. Each coil has 4 turns and a pitch (1) of 12 slots, (2) of 10 slots. The pole pitch is 15 in., and the length of the armature parallel to the shaft is 18 in. The effective length of the air gap is 0.5 in. Assume that the distribution of m.m.f. due to a single armature coil is rectangular. (*a*) The armature coils are connected to give a 2-phase winding. The phase currents are unbalanced, and, while each is 100 amp., they are displaced 60 deg. in phase instead of 90 deg. Plot the distribution of armature

m.m.f. along the air gap at each of six equally spaced intervals of time during the half-cycle. What is the maximum flux density in the air gap at each of these moments? What is the flux per pole at each of these moments? (*b*) The armature coils are connected to give a 3-phase, Y-connected winding. The phase currents are unbalanced and are 100, 100, and 141.4 amp., respectively. Plot the distribution of armature m.m.f. along the air gap at each of six equally spaced intervals of time during the half-cycle. What is the maximum flux density in the air gap at each of these moments? What is the flux per pole at each of these moments?

52. A 3-phase, Y-connected alternator has 15 slots per pole with 2 coil sides per slot. Each coil has 4 turns, and the coil pitch is 12 slots. The diameter of the armature at the air gap is D in., the length of the armature parallel to the shaft is L in., and the effective radial length of the air gap is g in. Assume that each coil produces a rectangular distribution of m.m.f., but neglect all of the harmonics.[1] Assume that the conductors of phase b are placed 120 deg. to the right of phase a. What is the maximum flux density in the air gap due to the armature currents at the moment that the currents in phases a and b are both in the same direction and are, respectively, 100 and 200 amp.? What is the angular position of this point of maximum flux density with respect to the conductors of phase a?

53. The currents in a 3-phase alternator are balanced. Assume that the flux distribution in the air gap due to one phase alone is sinusoidal. Plot the component distributions due to each phase (dotted) and the resultant distribution (full line) for the instants that the current in phase 1 is zero, one-half of its maximum value, and its maximum value. What part of the resultant flux links phase 1 at each of these instants?

54. A 3-phase, Y-connected alternator has 18 slots per pole, with 2 coil sides per slot. Each coil has 4 turns, and the coil pitch is 12 slots. The pole pitch is 16.25 in., the length of the armature core parallel to the shaft is 18 in., and the effective length of the air gap is 0.5 in. The armature currents are 120 amp. per phase. Assume that each coil produces a component distribution of m.m.f. that is rectangular, but neglect all of the harmonics.[1]

[1] The fundamental component of a rectangular distribution has a maximum value of $4/\pi$ of the ordinates of the rectangle.

Plot the distribution of armature m.m.f. along the air gap at each of six equally spaced time intervals during the half-cycle, beginning at the moment when the current in one phase, A, is passing through zero. What is the maximum flux density in the air gap at each of these moments? What is the angular position with respect to phase A of each of these points at which the flux density is a maximum? What is the flux per pole at each of these moments? What portion of the flux per pole links phase A at each of these moments?

55. A 2-phase, 100 kv.-a., 480-volt alternator has 12 slots per pole with 2 coil sides per slot. Each coil has 2 turns, and the coil pitch is 9 slots. The diameter of the armature core at the air gap is 26.4 in., its length parallel to the shaft is 5.75 in., and effective radial length of the air gap is 0.25 in. There are 8 poles. The armature currents are balanced and have their full-load value. Assume that each coil produces a component distribution of m.m.f. that is rectangular, but neglect all of the harmonics.[1]

Plot the distribution of armature m.m.f. along the air gap at each of six equally spaced time intervals during the half-cycle, beginning at the moment when the current in one phase, A, is passing through zero. What is the maximum flux density in the air gap at each of these moments? What is the angular position with respect to phase A of each of these points at which the flux density is a maximum? What is the flux per pole at each of these moments? What portion of the flux per pole links phase A at each of these moments?

56. A 3-phase, Y-connected alternator has 21 slots per pole with two coil sides per slot. Each coil has one turn and a coil pitch of 17 slots. The effective radial length of the air gap is 1 in. Assume that 90 per cent of the reluctance of the magnetic circuit is in the air gap. Also, assume that the distribution of flux in the air gap due to a winding consisting of a single coil per pole is rectangular, but neglect all of the harmonics.[1] The armature currents are unbalanced and are, respectively, 500, 500, and 707 amp. in phases 1, 2, and 3, with the current in the first phase leading that in the second. Compute the value and angular positions, measured from the center of the first phase belt, of the resulting maximum flux density in the air gap

[1] The fundamental component of a rectangular distribution has a maximum value of $4/\pi$ of the ordinates of the rectangle.

at each of six equally spaced time intervals in the cycle beginning at the moment when the current in the first phase is passing through zero.

57.[1] (*a*) In problem 34, what is the armature reaction in ampere-turns per pole when the alternator is delivering its rated load at unity power factor? (*b*) What are the leakage reactance volts at this load? The armature inductors are 41 in. long. Assume that the equivalent leakage flux is 7 lines per ampere per inch of inductor. (*c*) If the armature winding had been equally distributed in 5 adjacent slots instead of in 10, what would have been the leakage reactance volts at this load? Assume 7 leakage lines, as in (*b*).

58. (*a*) In problem 35, what is the armature reaction in ampere-turns per pole when the alternator is delivering 200 kw. at 0.8 power factor and its rated potential? (*b*) What are the leakage reactance volts at this load? The armature inductors are 23 in. long. Assume that the equivalent leakage flux is 8 lines per ampere per inch of inductor. (*c*) If the armature winding had been equally distributed in the 4 central slots, *i.e.*, with 4 inductors per slot, what would have been the leakage reactance volts at this load? Assume 8 leakage lines, as in (*b*).

59. (*a*) In problem 36, what is the armature reaction in ampere-turns per pole when the alternator is delivering full-load kilovolt-amperes? (*b*) What are the leakage reactance volts per phase at this load? Assume that the equivalent leakage flux is 96 lines per ampere per inductor. (*c*) If the armature winding had been concentrated, *i.e.*, with 1 slot per pole per phase, holding 22 inductors, what would have been the leakage reactance volts? Assume the same leakage flux per inductor as in (*b*).

60.[1] A 3-phase, Y-connected alternating-current generator which is rated to deliver 760 kv.-a. at 2200 volts has an armature with 6 slots per pole. There are 3 inductors in series per slot. The coil pitch is 6 slots.

What are the cross-magnetizing and demagnetizing ampere-turns per pole due to armature reaction when the alternator delivers its full-load current (*a*) if the power factor is such that the current in any phase reaches its maximum value of 60 deg. after the inductors of that phase pass the center of the pole, (*b*)

[1] See footnote, p. 109.

if the power factor is such that the current in any phase reaches its maximum value of 30 deg. before the inductors of that phase pass the center of the pole?

61.[1] A 3-phase, 1500-kv.-a., 5500-volt alternating-current generator has a field structure with 72 poles and an armature with 216 slots. There are 12 inductors in series per slot. The phase windings are connected in Y. (*a*) What are the cross-magnetizing and demagnetizing ampere-turns per pole due to armature reaction when the alternator delivers its full-load current at 0.85 power factor (inductive load)? Assume that for this power factor the current in any phase is 0.7 of its maximum value at the time the inductors of that phase are under the center of the pole. (*b*) What are the cross-magnetizing and demagnetizing ampere-turns per pole due to armature reaction when the alternator delivers its full-load current at 0.85 power factor (condensive load)? Assume that for this power factor the current in any phase is 0.2 of its maximum value at the time the inductors of that phase are midway between the poles.

DATA ON ALTERNATING-CURRENT GENERATORS

	No. 1	No. 2
Rated output, kilovolt-amperes	100	5,000
Phases	2	3, Y
Frequency	60	60
Line potential	480	6,600
Armature iron:		
Effective length of core	5.75 in.	17.5 in.
Diameter of core at air gap	26.4 in.	148 in.
Slots, open	96	360
Depth of slot	1.488 in.	2.2 in.
Width of slot	0.37 in.	0.58 in.
Field magnets:		
Poles	8	30
Pole arc: pole pitch	0.70	0.768
Armature copper:		
Inductors per slot	8 (2 in parallel)	4 (2 in parallel)
Size of inductor	No. 8 wire	$\frac{9}{64} \times \frac{7}{8}$ in. strap
Thickness of insulation between inductor and sides of slot	0.042 in.	0.114 in.
Mean length per turn	44.4 in.	107.26 in.
Coil pitch (slots)	9	10

[1] See footnote, p. 109.

62.[1] Calculate the cross-magnetizing and demagnetizing ampere-turns in alternator No. 1 for full-load current and such a power factor that the current is lagging and has a value of 0.70 of its maximum value in any phase when the inductors of that phase are opposite the center of the poles.

63.[1] Calculate the cross-magnetizing and demagnetizing ampere-turns in alternator No. 2 for full-load current and such a power factor that the current is lagging and has a value of 0.80 of its maximum value in any phase when the inductors of that phase are opposite the center of the poles.

64. A 25-cycle alternating-current generator has an armature core with slots that are 1.35 in. wide and 2.625 in. deep. There are 4 inductors in series per slot. (*a*) Calculate the slot reactance per inch of slot on the assumptions that the path of the leakage flux across the inductors is parallel to the bottom of the slot, that the permeability of the iron is great, and that the inductors completely fill the slot. (*b*) If the slot reactance is calculated on the assumption that all of the leakage flux per slot is linked with all of the inductors in that slot, what value of leakage flux per ampere per inch of inductor will give the same slot reactance as calculated by the preceding method?

65. A 125-cycle alternating-current generator has an armature core with slots which are 1.0 in. wide and 3.5 in. deep. Each slot holds 12 inductors in series which completely fill it. (*a*) Calculate the leakage reactance per inch of slot on the assumptions that the path of the leakage flux across the inductors is parallel to the bottom of the slot and that the permeability of the iron is great. (*b*) If the 12 inductors fill the slot to a depth of but 2.5 in., calculate the leakage reactance per inch of slot on the same assumptions.

66. A 60-cycle alternating-current generator has an armature core with slots which are 1.1 in. wide, 2.75 in. deep, and 15 in. long. There are 6 inductors in series per slot which fill it to a depth of 2.0 in. (*a*) Calculate the slot reactance on the assumptions that the path of the leakage flux between the sides of the slot is parallel to the bottom of the slot and that the permeability of the iron is great. (*b*) If the slot reactance is calculated on the assumption that all of the leakage flux per slot is linked with all of the inductors in that slot, what value of leakage flux per ampere per inch of inductor will give the same slot reactance as calculated by the preceding method?

[1] See footnote, p. 109.

67. A 3-phase, 25-cycle alternator is rated to deliver 850 kv.-a. at 5000 volts. The slots in the armature core are 1.31 in. wide and 3.625 in. deep. The gross length of the armature core is 14.5 in., and the effective length, deducting for the ventilating ducts and the insulation on the laminations, is 10.75 in. There are 14 inductors in series per slot which occupy a space 0.75 by 2.75 in. The thickness of the insulation between the inductors and the armature core is the same at the sides and at the bottom of the slot. The mean length of 1 turn is 93 in. Each coil consists of 14 turns. (*a*) Calculate the leakage reactance per coil on the following assumptions: Where the inductors are embedded in iron, the path of the leakage flux between the sides of the slot is parallel to the bottom of the slot. For the portions of the coil that are not embedded in the armature core, the leakage flux links with all of the turns in that coil and has a value of 0.8 line per ampere per inch of turn. (*b*) If the leakage reactance is calculated on the assumptions that all of the leakage flux per coil links with all of the turns in the coil and that the length of the coil is but twice the length of the inductor, *i.e.*, twice the gross length of the armature core, what value of leakage flux per ampere per inch of inductor will give the same value of leakage reactance as calculated by the preceding method?

68.[1] (*a*) Calculate the slot and coil-end leakage reactance for alternator 1 (see problem 62). Use the most exact method at your command for the data given. (*b*) Calculate the slot and coil-end leakage reactance for alternator 2 (see problem 63). Use the most exact method at your command for the data given.

69. (*a*) In problem 43, what is the armature reaction in ampere-turns per pole when the alternator is delivering 7650 kw. at 0.9 power factor and its rated potential? (*b*) What are the leakage reactance volts per phase at this load? The armature inductors are 48 in. long. Assume that the equivalent leakage flux is 6.5 lines per ampere per inch of inductor.

70.[1] (*a*) If the equivalent leakage flux per ampere per conductor per inch of core is 10 lines, what is the leakage reactance per phase of alternator 1? What is the armature reaction in ampere-turns per pole when it is delivering its rated kilovolt-amperes? (*b*) If the equivalent leakage flux per ampere per conductor per inch of core is 10 lines, what is the leakage reactance per phase

[1] See table on page 63.

of alternator 2? What is the armature reaction in ampere-turns per pole when it is delivering its rated kilovolt-amperes?

71. In problem 38, what is the armature reaction in ampere-turns per pole per ampere of armature current? If the equivalent leakage flux is ϕ lines per ampere per conductor, what is the leakage reactance per phase?

72. If the equivalent leakage flux per ampere per inch of core is ϕ, what is the leakage reactance per phase of alternator A, . . . D, . . . or H? What is the armature reaction in ampere-turns per pole?

73. If alternator A, . . . D, . . . or H has X per cent leakage reactance per phase, what is the equivalent leakage flux per ampere per conductor per inch of core?

74. A 5000-kv.-a., 3-phase, Y-connected, 6600-volt, 60-cycle alternator has 12 slots per pole with 2 series conductors per slot. The coil pitch is 10 slots. There are 30 poles. The pole pitch is 15.5 in., and its effective length parallel to the shaft is 17.5 in. The mean radial length of the air gap is 0.5 in. Assume that the entire reluctance of the magnetic circuit is in the air gap and that each coil produces a rectangular distribution of m.m.f., but neglect all harmonics. With full-load armature current but with no field current, what is the maximum flux density in the air gap? What is the flux per pole due to the armature currents? What is the e.m.f. per phase generated in the armature winding by this flux?

75. A 100-kv.-a., 2-phase, 480-volt, 60-cycle alternator has 96 slots with 4 series conductors per slot. The coil pitch is 9 slots. There are 8 poles. The diameter of the armature core at the air gap is 26.4 in., and the effective length of the core parallel to the shaft is 5.75 in. The mean radial length of the air gap is 0.25 in. Assume that the entire reluctance of the magnetic circuit is in the air gap and that each coil produces a rectangular distribution of m.m.f., but neglect all of the harmonics. With full-load armature current but with no field current, what is the maximum flux density in the air gap? What is the flux per pole due to the armature currents? What is the e.m.f. per phase generated in the armature winding by this flux?

76. An 8000-kv.-a., 3-phase, Y-connected, 11,000-volt, 60-cycle alternator has 288 slots with 6 series conductors per slot. The coil pitch is 4 slots. There are 64 poles. The diameter of the armature core at the air gap is 177 in., and the effective

length of the core parallel to the shaft is 35 in. The mean radial length of the air gap is 0.37 in. Assume that the entire reluctance of the magnetic circuit is in the air gap and that each coil produces a rectangular distribution of m.m.f., but neglect all of the harmonics. With the field current adjusted to give the rated terminal potential at no load, what is the ratio of the component fluxes in the air gap due to full-load armature current and to the field current?

77. Compute the equivalent leakage lines per ampere per inch of embedded conductor that will give the same leakage reactance per phase as determined from the open-circuit and zero-power factor characteristics (*a*) for alternator A, (*b*) for alternator B, (*c*) for alternator C, (*d*) for alternator D, (*e*) for alternator E, (*f*) for alternator F, (*g*) for alternator G, (*h*) for alternator H.

78. By comparing the value of the armature reaction as computed from the winding data and as determined by test, determine the error in the constant "0.707" for alternator A, . . . D, . . . or H.

79.[1] From test data, determine the per cent leakage reactance, the per cent synchronous reactance (A.I.E.E. definition), and the per cent armature reaction for alternator A, . . . D, . . . or H.

80. When the coil pitch of a 3-phase alternator is unity, the ratio of the leakage reactance to the synchronous reactance is 0.25. What will be this ratio if the coil pitch is reduced to five-sixths? What will be the ratio of the synchronous reactances in the two cases? Assume that the equivalent leakage flux per ampere per conductor and the saturation of the magnetic circuit are the same in each case.

81. When the coil pitch of a 3-phase alternator is unity, the short-circuit current with normal field excitation is 2.5 times the rated full-load current. The ratio of the leakage reactance to the synchronous reactance is 0.30. If this alternator is rewound with coils which have the same number of turns but a pitch of five-sixths, what will be the short-circuit current with the field current unchanged? Assume that the equivalent leakage flux per ampere per conductor is the same in each case.

[1] The per cent reactance is the per cent ratio of the reactance drop with full-load current to the rated potential. The per cent armature reaction is the per cent ratio of the armature ampere turns with full-load current to the field ampere-turns necessary to give rated potential at no load.

82. A special 60-cycle generator has a field structure with 6 poles and an armature with 72 slots. There are 9 inductors in series per slot. The coils in adjacent slots are connected in series by pairs so that each of the 6 independent armature windings thus formed has a spread of one-sixth and a pitch of 1.0. When the 6 windings are arranged to form a 3-phase, Y-connected armature winding, the synchronous reactance drop is 46 volts for an armature current of 30 amp. Assume that the armature leakage flux is 72 lines per inductor per ampere and that the approximate formula for armature reaction (given in footnote I, p. 109) holds in every case. (*a*) What are the synchronous-reactance volts with an armature current of 30 amp. when the 6 armature windings are connected in series to form a single-phase, open-circuit armature winding? (*b*) The synchronous-reactance volts are 24 per cent of the open-circuit phase potential when the armature winding is connected in Y. With the same field current, what per cent of the open-circuit armature potential will the synchronous-reactance volts be when the windings are connected to form a single-phase, open-circuit armature winding?

83. (*a*) In problem 82, what are the synchronous-reactance volts per phase with an armature current of 30 amp. when the 6 windings are connected to form a 2-phase armature winding? (*b*) With the same field current as in 82(*b*), what per cent of the open-circuit armature potential will the synchronous-reactance volts be when the windings are connected to form a 2-phase armature winding?

84. Two 3-phase, 60-cycle alternating-current generators have the same current and potential rating. The first has 12, and the second has 9 slots per pole. The coil pitches are, respectively, 10 and 8 slots. Each alternator has the same number of turns per phase. The first has 4 poles, and the second 6, but the dimensions of the magnetic circuit are such that the same number of ampere-turns on the field produces the same flux per pole in each. The shape of the armature slots is such that the leakage flux per ampere per inductor is also the same for each.

The armature leakage reactance and the synchronous reactance of the first alternator are, respectively, 0.54 ohm and 2.13 ohms. Under the same condition of saturation, what are the corresponding constants of the second alternator?

85. A 17,000-kv.-a., 3-phase, Y-connected, 6600-volt, 50-cycle alternator has 216 slots with 2 series conductors per slot. The coil pitch is 12 slots. There are 16 poles. The diameter of the armature core at the air gap is 135 in., and the effective length of the core parallel to the shaft is 30 in. The mean radial length of the air gap is 1.25 in. Assume that the entire reluctance of the magnetic circuit is in the air gap and that each coil produces a reactangular distribution of m.m.f., but neglect all of the harmonics. Also, assume that the equivalent leakage flux is 15 lines per ampere per inch of embedded conductor. (*a*) Compute the leakage reactance of this alternator. (*b*) Compute the synchronous reactance of this alternator.

86. The coils of an alternator may be connected for 3-phase, Y, or 2-phase. There are 12 slots per pole, and the coil pitch is 10 slots. What is the ratio of the phase potentials with normal field current for the two arrangements of the armature coils? What is the ratio of the per cent leakage reactance for the 3-phase to that for the 2-phase arrangement of the armature coils? What is the ratio of the per cent synchronous reactance for the 3-phase to that for the 2-phase arrangement of the armature coils? Assume that the equivalent leakage flux per ampere per conductor, the rated armature current, and the normal field current are the same in both cases.

87. The coils of an alternator may be connected for 3-phase, Y, or 2-phase. There are 18 slots per pole, and the coil pitch is 15 slots. What is the ratio of the phase potentials with normal field current for the two arrangements of the armature coils? What is the ratio of the per cent leakage reactance for the 3-phase to that for the 2-phase arrangement of the armature coils? What is the ratio of the synchronous reactance for the 3-phase to that for the 2-phase arrangement of the armature coils? Assume that the equivalent leakage flux per ampere per conductor, the rated armature current, and the normal field current are the same in both cases.

88. A 3-phase, Δ-connected alternating-current generator is rated to deliver 15 kv.-a. at 230 volts when running at a speed of 1200 r.p.m. There are 6 field poles each of which is wound with 398 turns. The armature has 72 slots with 8 inductors in series per slot. Each inductor is 5 in. long. The hot resistance of the armature measured between any two terminals is 0.126 ohm. The effective resistance is 1.6 times the ohmic resistance.

In calculating the leakage reactance, assume 8 leakage lines per ampere per inch of inductor. The open- and short-circuit characteristics are given by the following data:

Field current	Open circuit — Terminal potential	Short circuit — Armature current
2.0	104	22
4.0	199	44
5.0	240	55
6.0	275	
7.5	315	

(*a*) Calculate the field current of this generator by the general method for an inductive load of 15 kw. at 0.8 power factor. What is the regulation calculated by this method? (*b*) Calculate the field current of this generator for the specified load by the synchronous-impedance method. What is the regulation calculated by this method? (*c*) Calculate the field current of this generator for the specified load by the m.m.f. method. What is the regulation calculated by this method?

89. A 760-kv.-a., 2200-volt alternating-current generator delivers energy directly to a 3-phase, 50-cycle system. The neutral of the generator is grounded. The field structure consists of 64 poles, each of which is wound with 50 turns. The armature core has 384 slots with 3 inductors in series per slot. The length of the armature core parallel to the shaft is 10 in. The effective resistance of the armature winding is 0.172 ohm per phase. In calculating the leakage reactance, assume 6.5 leakage lines per ampere per inch of slot per inductor. The open- and short-circuit characteristics are given by the following data:

Field current	Open circuit — Terminal potential	Short circuit — Armature current
50	1,060	280
80	1,650	450
100	1,950	
120	2,160	
150	2,420	
200	2,650	

(*a*) Calculate the field current of this generator for 25 per cent overload current at unity power factor by the general method. What is the regulation calculated by this method? (*b*) Calculate the field current of this generator for the specified load by the synchronous-impedance method. What is the regulation calculated by this method? (*c*) Calculate the field current of this generator for the specified load by the m.m.f. method. What is the regulation calculated by this method?

90. A 3-phase, Y-connected, 1500-kv.-a., 5500-volt alternating-current generator is driven by a 2000-hp. reciprocating engine which runs at 83 r.p.m. at full load. The field structure has 72 poles each of which is wound with 35 turns. The armature core has 1 slot per pole per phase with 12 inductors in series per slot. Each inductor is 9 in. long. The armature winding has an effective resistance of 0.36 ohm per phase. In calculating the leakage reactance, assume 7.5 equivalent leakage lines per ampere per inch of inductor. The data for the open- and short-circuit characteristics are

Field current	Open circuit: Terminal potential	Short circuit: Armature current
150	5,100	300
200	5,900	400
250	6,500	
300	6,800	
350	7,100	

(*a*) Calculate the field current of this generator by the general method for 20 per cent overload current at 0.85 power factor (inductive load). What is the regulation calculated by this method? (*b*) Calculate the field current of this generator for the specified load by the synchronous-impedance method. What is the regulation calculated by this method? (*c*) Calculate the field current of this generator for the specified load by the m.m.f. method. What is the regulation calculated by this method?

91. A 3750-kv.-a. alternating-current generator delivers energy at 2200 volts to a 2-phase, 30-cycle system. The field structure

has 20 poles each of which is wound with 60 turns. The armature has 360 slots with 1 inductor per slot. Each inductor is 20.5 in. long. The armature resistance by direct-current measurement is 0.0196 ohm per phase at 25°C. Assume that the ratio of effective resistance to ohmic resistance is 1.3 at 25°C. In calculating the leakage reactance, assume that the leakage flux is 6.5 lines per ampere per inch of inductor. The data for the open- and short-circuit characteristics are

Field ampere-turns per pole	Open circuit	Short circuit
	Terminal potential	Armature current
4,000	680	606
8,000	1,360	1,210
12,000	2,000	
16,000	2,480	
18,000	2,660	

(*a*) Calculate the field current of this generator for a condensive load of 3500 kw. at 0.92 power factor by the general method. What is the regulation calculated by this method? Assume that the temperature of the armature windings is 70°C. (*b*) Calculate the field current of this generator for the specified load by the synchronous-impedance method. What is the regulation calculated by this method? (*c*) Calculate the field current of this generator for the specified load by the m.m.f. method. What is the regulation calculated by this method?

92. A 3-phase waterwheel generator whose armature winding is Y-connected is rated to deliver 5000 kv.-a. at 6600 volts. Its normal speed is 240 r.p.m. The field structure has 30 poles with 67.5 turns per pole. The armature core has 360 slots with 2 inductors in series per slot. The length of the armature core is 21.5 in. The measured resistance of the armature between any two terminals is 0.0836 ohm at 25°C. The ratio of effective resistance to ohmic resistance is 1.65 at 25°C. In calculating the leakage reactance, assume that the leakage flux is 6.5 lines per ampere per inch of slot per inductor.

The open- and short-circuit characteristics are given by the following data:

Field current	Open circuit	Short circuit
	Terminal potential	Armature current
100	4,800	680
150	6,500	1,020
200	7,400	
250	7,900	

(*a*) Calculate the field current of this generator by the general method for full-load kilovolt-amperes at 0.8 power factor (inductive load). What is the regulation calculated by this method? Assume that the temperature of the armature windings is 70°C. (*b*) Calculate the field current of this generator for the specified load by the synchronous-impedance method. What is the regulation calculated by this method? (*c*) Calculate the field current of this generator for the specified load by the m.m.f. method. What is the regulation calculated by this method?

93. A 3-phase, Y-connected alternating-current generator is rated to deliver 1000 kv.-a. at 13,800 volts. The armature has an effective resistance of 2.18 ohms per phase. The data for the open-circuit characteristic and the full-load-current saturation curve at zero power factor are

Field current	Open-circuit terminal potential	Saturation curve, 42 amperes at zero power factor
41 2		0
50	8,800	.
110	15,600	10,750
140	17 250	13,250
180	18,900	15,600

Calculate the field current for an inductive load of 50 amp. at 0.85 power factor.

94. A 3-phase waterwheel generator is rated to deliver 5000 kv.-a. at 6600 volts. The armature winding is Y-connected and has an effective resistance of 0.081 ohm per phase. The data for the open-circuit characteristic and the full-load-current saturation curve at zero power factor are

Field current	Open-circuit terminal potential	Saturation curve, 438 amperes at zero power factor
64	3,050	0
100	4,800	1,800
150	6,500	4,200
200	7,400	5,700
275	8,150	6,900

Calculate the field current for an inductive load of 500 amp. at 0.8 power factor?

95. Compute the field current of alternator A, . . . D, . . . or H when delivering rated kilovolt-amperes (*a*) at a terminal power factor of unity, (*b*) at a terminal power factor of 0.8 to an inductive load, (*c*) at a terminal power factor of 0.8 to a capacitive load, (1) by the general method, (2) by the synchronous-impedance (A.I.E.E.) method, (3) by the m.m.f. method. What is the regulation? Assume that the temperature of the armature winding is 80°C.

96. A 2-phase, 60-cycle, alternating-current generator is rated to deliver 100 kv.-a. at 480 volts. The armature has an effective resistance of 0.138 ohm and a leakage reactance of 0.159 ohm per phase. When the power factor of the load is 0.8, the armature demagnetizing ampere-turns are 11.8, and the cross-magnetizing ampere-turns are 15.2 per pole per ampere. The field poles are each wound with 265 turns. The data for the open-circuit characteristic are

Field current	Open-circuit potential
10	400
15	500
20	560
25	598

Calculate the field current of this generator when delivering full-load current at 0.8 power factor (inductive load). (*a*) Assume that the cross-magnetizing and demagnetizing ampere-turns act on magnetic circuits of the same reluctance as that of the resultant field. This is a modification of the general method.

(*b*) Assume that the cross-magnetizing ampere-turns act on a magnetic circuit whose reluctance is determined by the lower part of the saturation curve and that the demagnetizing ampere-turns act on the same magnetic circuit as do the impressed field ampere-turns. This is the Blondel method.

97. A 3-phase, 25-cycle alternating-current generator is rated to deliver 850 kv.-a. at 5000 volts. The armature windings are connected in Y and have an effective resistance of 0.398 ohm and a leakage reactance of 1.46 ohms per phase. When the power factor of the load is unity, the armature demagnetizing ampere-turns are 5.8, and the cross-magnetizing ampere-turns are 31 per pole per ampere. The field poles are each wound with 79.5 turns. The data for the open-circuit characteristic are

Field ampere turns per pole	Open-circuit terminal potential
6,000	4,330
10,000	5,460
12,000	5,800
14,000	6,060

Calculate the field current of this generator when delivering 30 per cent overload current at unity power factor. (*a*) Assume that the cross-magnetizing and demagnetizing ampere-turns act on magnetic circuits of the same reluctance as that of the resultant field. This is a modification of the general method. (*b*) Assume that the cross-magnetizing ampere-turns act on a magnetic circuit whose reluctance is determined by the lower part of the saturation curve and that the demagnetizing ampere-turns act on the same magnetic circuit as do the impressed field ampere-turns. This is the Blondel method.

98. A 3-phase, Y-connected alternating-current generator is rated to deliver 1640 kv.-a. at 13,500 volts. The armature has an effective resistance of 1.52 ohms per phase and a synchronous reactance of 37.4 ohms per phase. What is the excitation e.m.f. (*a*) for an inductive load taking 1500 kw. at 0.85 power factor, (*b*) for a condensive load taking 1500 kw. at 0.85 power factor?

99. A 2-phase alternating-current generator is rated to deliver 3500 kw. at 10,000 volts. The armature has an effective resist-

ance of 0.64 ohm per phase and a synchronous reactance of 23.7 ohms per phase. What is the excitation e.m.f. of this alternator (*a*) for a non-inductive load taking the rated kilovolt-amperes, (*b*) for an inductive load taking the rated kilovolt-amperes at zero factor, (*c*) for a condensive load taking the rated kilovolt-amperes at zero power factor?

100. A 760-kv.-a., 2200-volt, 3-phase alternating-current generator has an effective armature resistance of 0.17 ohm per phase. The armature winding is connected in Y. With the armature short circuited, the armature current is 338 amp. when the field current is 60 amp. The open-circuit characteristic data are

Field current	Open-circuit terminal potential
50	1,060
80	1,650
100	1,950
120	2,160
150	2,420
200	2,650

What is the excitation e.m f. of this generator, calculated by the m.m.f. method, (*a*) for an inductive load which requires full-load current at 0.5 power factor, (*b*) for a condensive load which requires full-load current at 0.5 power factor?

101. A 3-phase, Δ-connected alternating-crurent generator has a full-load capacity of 15 kv.-a. at 230 volts. The effective armature resistance and synchronous reactance are, respectively, 0.302 ohm and 4.36 ohms per phase. Three reactors each of which has an effective resistance of 2.5 ohms and a reactance of 10 ohms are connected in Δ across the terminals of the generator. (*a*) If the terminal potential is adjusted to its rated value, to what value will it rise when the coils are removed? (*b*) If the coils are reconnected in Y and the terminal potential adjusted as before, to what will it rise when the coils are removed? (*c*) What is the power output of the generator in each case?

102. In problem 101, if the open-circuit potential of the generator is adjusted to 300 volts, to what will it fall when the coils are connected in Δ across the terminals? What is the power output of the generator?

103. A 3-phase, 1500-kv.-a., 5500-volt alternating-current generator delivers full-load current to an inductive load at 0.85 power factor. The effective resistance and synchronous reactance of this alternator are, respectively, 0.36 ohm and 6.5 ohms per phase. The armature winding is Y-connected. With the field excitation unchanged, what will be the terminal potential if the alternator delivers its rated current to a condensive load at 0.85 power factor?

104. Construct the zero-power-factor saturation curve for alternator A, . D, . . . or H when delivering rated current to a condensive load. Use (*a*) the general method (Potier triangle), (*b*) the synchronous-impedance method (A.I.E.E), (*c*) the m.m.f. method.

105. Construct the zero-power-factor saturation curve for alternator A, . . . D, . . . or H when delivering rated current to an inductive load at a frequency (*a*) 20 per cent below its rated value, (*b*) 20 per cent above its rated value. Use (1) the general method (Potier triangle) (2) the synchronous-impedance method (A.I.E.E.), (3) the m.m.f. method.

106. Construct a load saturation curve of alternator A, . . . D, . . . or H when delivering rated current at a terminal power factor of (*a*) unity, (*b*) 0 8 to an inductive load, (*c*) 0.8 to a capacitive load. Use (1) the general method (Potier triangle), (2) the synchronous-impedance method (A.I.E.E.), (3) the m.m.f. method.

107. What are the per cent leakage reactance, per cent armature reaction and per cent synchronous reactance at normal saturation (A.I.E.E.) for alternator A, . . . D, . . . or H?

108. A 3-phase alternator has a resistance of 1.0 per cent, a leakage reactance of 15 per cent, and a synchronous reactance of 60 per cent. When this alternator is delivering its rated kilovolt-amperes at a terminal power factor of (*a*) unity, (*b*) 0.8 to an inductive load, (*c*) 0.8 to a capacitive load, at what point in the air gap with respect to the center of the field poles is the flux density a maximum?

109. At what point in the air gap with respect to the center of the field poles of alternator A, . . . D, . . . or H is the flux density a maximum when it is delivering its rated kilovolt-amperes at a terminal power factor of (*a*) unity, (*b*) 0.8 to an inductive load, (*c*) 0.8 to a capacitive load?

110. A 3-phase alternator has a resistance of 1.0 per cent, a leakage reactance of 15 per cent, and a synchronous reactance of 60 per cent. When this alternator is delivering its rated kilovolt-amperes at a terminal power factor of (*a*) unity, (*b*) 0.8 to an inductive load, (*c*) 0.8 to a capacitive load, where, with respect to the center of the field poles, is a phase belt at the moment the current in it is passing through its maximum value?

111. At what point in the air gap with respect to the center of the field poles of alternator A, . . . D, . . . or H will a phase belt be at the moment that the current in it is passing through its maximum value if the alternator is delivering its rated kilovolt-amperes at a terminal power factor of (*a*) unity, (*b*) 0.8 to an inductive load, (*c*) 0.8 to a capacitive load? Use (1) the general method (Potier triangle), (2) the synchronous-impedance method (A.I.E.E.), (3) the m.m.f. method.

112. A 3-phase alternator has a resistance of 1.0 per cent, a leakage reactance of 15 per cent, and a synchronous reactance of 60 per cent. At what terminal power factor must this alternator deliver its rated kilovolt-amperes in order that the phase current shall be passing through its maximum value at the moment that the phase belt is at the center of a field pole?

113. At what terminal power factor must alternator A, . . . D, . . . or H be delivering its rated kilovolt-amperes in order that the phase current shall be passing through its maximum value at the moment that the phase belt is at the center of a field pole? Use (1) the general method (Potier triangle), (2) the synchronous-impedance method (A.I.E.E.), (3) the m.m.f. method.

114. A 3-phase alternator has a resistance of 1.0 per cent, a leakage reactance of 15 per cent, and a synchronous reactance of 60 per cent. When this alternator is delivering its rated kilovolt-amperes, at a terminal power factor of (*a*) unity, (*b*) 0.8 to an inductive load, (*c*) 0.8 to a capacitive load, what per cent of its maximum value is the phase current at the moment that the phase belt is passing the center of the field poles?

115. What per cent of its maximum value is the phase current at the moment that the phase belt is passing the center of the field poles when alternator A, . . . D, . . . or H is delivering its rated kilovolt-amperes at a terminal power factor of (*a*) unity, (*b*) 0.8 to an inductive load, (*c*) 0.8 to a capacitive load? Use (1) the general method (Potier triangle), (2) the synchronous-impedance method (A.I.E.E.), (3) the m.m.f. method.

116. Two 3-phase, Y-connected, 2200-volt alternators have their rotors rigidly coupled together and so adjusted that at no load on either their terminal potentials are in phase. Their neutrals are connected, and a voltmeter V is connected between two corresponding line terminals. The first alternator has a resistance of 1.0 per cent, a leakage reactance of 15 per cent, and a synchronous reactance of 60 per cent. What is the reading of the voltmeter V when the first alternator delivers its rated kilovolt-amperes at a terminal power factor of (*a*) unity, (*b*) 0.8 to an inductive load, (*c*) 0.8 to a capacitive load, and the second alternator is operated at its rated terminal potential but with no connected load?

117. Two 3-phase, Y-connected alternators have their rotors rigidly coupled together and so adjusted that at no load on either their terminal potentials are in phase. Their neutrals are connected, and a voltmeter V is connected between two corresponding line terminals. The field currents are adjusted so that the terminal potentials of the alternators are equal. The first alternator delivers its rated kilovolt-amperes at a terminal power factor of (*a*) unity, (*b*) 0.8 to an inductive load, (*c*) 0.8 to a capacitive load, while the second alternator is operated at no load. What is the reading of the voltmeter V if the first alternator is A, . . . D, . . or H? Use (1) the general method (Potier triangle), (2) the synchronous-impedance method (A.I.E.E.), (3) the m.m.f. method.

118. A 3-phase alternator has a resistance of 1.5 per cent, a synchronous reactance of 35 per cent at an internal power factor of unity, and a synchronous reactance of 60 per cent at an internal power factor of zero. When this alternator delivers its rated kilovolt-amperes at a terminal power factor of (*a*) unity, (*b*) 0.8 to an inductive load, (*c*) 0.8 to a capacitive load, what per cent of its normal value is the field current? Use the open-circuit characteristic given on page 112.

119. A 3-phase alternator has a resistance of 1.5 per cent and a synchronous reactance of 75 per cent, as determined by the open-circuit and zero-power-factor characteristics. The synchronous reactance at an internal power factor of unity is 60 per cent as great. When this alternator delivers its rated kilovolt-amperes at a terminal power factor of (*a*) unity, (*b*) 0.8 to an inductive load, (*c*) 0.8 to a condensive load, what per

cent of its normal value is the field current? Use the open-circuit characteristic given on page 112.

120. A 3-phase alternator has a resistance of 1.5 per cent, a synchronous reactance of 30 per cent at an internal power factor of unity, and a synchronous reactance of 55 per cent at an internal power factor of zero. The alternator is delivering rated kilovolt-amperes at a terminal power factor of (*a*) unity, (*b*) 0.8 to an inductive load, (*c*) 0.8 to a condensive load. Compare the magnitude and phase of the excitation e.m.f. with respect to the terminal potential when computed by the synchronous-impedance method, using the synchronous reactance at zero power factor, and by the double-reaction method.

121. A 3-phase alternator has a resistance of 1.5 per cent and a synchronous reactance of 70 per cent, as determined by the open-circuit and zero-power-factor characteristics. The synchronous reactance at an internal power factor of unity is 65 per cent as great. The alternator is delivering rated kilovolt-amperes at a terminal power factor of (*a*) unity, (*b*) 0.8 to an inductive load, (*c*) 0.8 to a condensive load. Compare the magnitude and phase of the excitation e.m.f. with respect to the terminal potential when computed by the synchronous-impedance method, using the synchronous reactance at zero power factor, and by the double reaction method.

122. A 3-phase alternator has a resistance of 1.5 per cent, a leakage reactance of 10 per cent, a synchronous reactance of 35 per cent at an internal power factor of unity, and a synchronous reactance of 60 per cent at an internal power factor of zero. The alternator is delivering rated kilovolt-amperes at a terminal power factor of (*a*) unity, (*b*) 0.8 to an inductive load, (*c*) 0.8 to a compacitive load. Compare the magnitudes and compute the relative phase of the components of air-gap flux due to the field current and to the armature currents. Use (1) the synchronous-impedance method with a synchronous reactance of 60 per cent, (2) the double-reaction method.

123. A 3-phase alternator has a resistance of 1.5 per cent, a leakage reactance of 15 per cent, a synchronous reactance of 40 per cent at an internal power factor of unity, and a synchronous reactance of 65 per cent at an internal power factor of zero. The alternator is delivering rated kilovolt-amperes at a terminal power factor of (*a*) unity, (*b*) 0.8 to an inductive load, (*c*) 0.8 to a condensive load. Compare the magnitudes and compute

the relative phase of the components of air-gap flux due to the field current and to the armature currents. Use (1) the synchronous impedance method with a synchronous reactance of 65 per cent, (2) the double-reaction method.

124. A special 6-pole, 60-cycle alternating-current generator has 6 similar and independent armáture windings. The windings are equally spaced so that their potentials differ by 30 deg.

On the basis of equal armature and field heating losses and of equal frequencies, compare the rated outputs—kilovolt-amperes and terminal potential—of this alternator when the windings are connected (1) for an open-coil single-phase winding, and (2) for a 2-phase winding.

125. (*a*) In problem 124, compare the rated outputs on the same basis when the windings are connected (1) for an open-coil single-phase winding, and (2) for a 3-phase mesh winding. (*b*) Compare the rated outputs on the same basis when the windings are connected (1) for an open-coil single-phase winding, and (2) for a 3-phase star winding.

126. In problem 124, compare the rated outputs on the same basis when the windings are connected (1) for a 2-phase winding, and (2) for a 3-phase star winding.

127. The armature coils of an alternator may be connected for either 2-phase or 3-phase. On the basis of the same armature heating losses, the same air-gap flux, and the same frequency, what will be the relative ratings for these two methods of connection?

128. An alternator has 18 slots per pole and coils with a pitch of 15 slots. The coils may be connected for either 2-phase or 3-phase. On the basis of the same armature heating losses, the same air-gap flux, and the same frequency, what will be the relative kilovolt-ampere ratings for these two methods of connection?

129. When the proper commutator segments of a direct-current generator are connected to slip rings, the armature will deliver balanced polyphase power. On the basis of the same armature heating losses, the same air-gap flux, and the same speed, compare the volt-ampere rating as a direct-current generator with the volt-ampere rating as (*a*) a 3-phase alternator, (*b*) a 4-phase alternator, (*c*) a 6-phase alternator.

130. When the proper commutator segments of a direct-current generator are connected to slip rings, the armature will

deliver balanced polyphase power. The armature has 18 slots per pole with 2 coil sides per slot and a coil pitch of 17 slots. On the basis of the same armature heating losses, the same air-gap flux, and the same speed, compare the potential and current ratings as a direct-current generator with the potential and current rating as (*a*) a 3-phase alternator, (*b*) a 4-phase alternator, (*c*) a 6-phase alternator.

131. Concerning the alternator described in problem 88, the following additional data are given: The field current is supplied at 110 volts. The friction and windage loss is 310 watts at normal speed, and the core loss due to rotation is 480 watts for an armature generated e.m.f. of 240. Assume that the core loss is constant. What is the efficiency of this alternator at the load described in problem 88? Calculate the field current by (*a*) the synchronous-impedance method, (*b*) the m.m.f. method.

132. Concerning the alternator described in problem 89, the following additional data are given: The resistance of the field circuit is 0.516 ohm. The friction and windage loss is 6.2 kw. at normal speed. The core loss due to rotation is 11.0 kw. at 2200 volts and may be assumed to vary as the square of the generated armature e.m.f. (*a*) What is the efficiency of this generator at the load described in problem 89? (*b*) What is the efficiency of this generator when delivering the same current at 0.80 power factor to an inductive load?

Calculate the field current by (1) the genera lmethod, (2) the m.m.f. method.

133. Concerning the alternator described in problem 90, the following additional data are given: The resistance of the field circuit is 0.376 ohm. The friction and windage loss is 8.4 kw. The core loss due to rotation is 20.2 kw. at 5500 volts and should be assumed to vary as the square of the generated armature e.m.f. What is the efficiency of this generator (*a*) at the load described in problem 90? (*b*) when delivering the same power at unity power factor? Calculate the field current (1) by the synchronous-impedance method. (2) by the m.m.f. method.

134. The full-load capacity of a 3-phase, 25-cycle alternating-current generator is 850 kv.-a. at 5000 volts. The armature windings are connected in Y and have an effective resistance of 0.398 ohm per phase. The synchronous reactance is 15.4 ohms per phase. With the armature short circuited, the armature current is 108 amp. when the field current is 50 amp. The

resistance of the field circuit is 0.82 ohm. The friction and windage is 7.6 kw. The core loss due to rotation is 20.2 kw. at 5200 volts and may be assumed to be constant. The open-circuit characteristic is given by the following data:

Field current	Open-circuit terminal potential
125	5,460
150	5,800
175	6,060

What is the efficiency of this generator when delivering 10 per cent overload current at 0.80 power factor to an inductive load? Calculate the field current by (1) the synchronous-impedance method, (2) the m.m.f. method.

135. Concerning the alternator described in problem 91, the following additional data are given: The resistance of the field circuit is 0.37 ohm. The friction and windage is 19 kw. The core loss is given by

Terminal potential on open circuit	Core loss, kilowatts
1,360	18.0
2,000	36.5
2,480	60 0

What is the efficiency of this generator for the load described in problem 91? Calculate the field current by (1) the general method, (2) the synchronous-impedance method, and (3) the m.m.f. method.

136. Concerning the alternator described in problem 93, the following additional data are given: The resistance of the field circuit is 0.541 ohm. The friction and windage loss is 9.2 kw. The core loss is given by

Terminal potential on open circuit	Core loss, kilowatts
8,800	7.5
13,000	16.6
15,600	25.4
17,250	33.5

What is the efficiency of this generator for the load described in problem 93?

137. Concerning the alternator described in problem 94, the following additional data are given: The resistance of the field circuit is 0.549 ohm at 25°C. The temperature of the field under load conditions is 68°C. The friction and windage loss is 38 kw. The core loss is given by

Terminal potential on open circuit	Core loss, kilowatts
4,800	45
6,000	73
6,600	90
7,500	123

What is the efficiency of this generator for the load described in problem 94?

138. What is the efficiency of alternator A, . . . D, . . . or H when delivering its rated kilovolt-amperes at (*a*) unity power factor, (*b*) 0.8 power factor to an inductive load, (*c*) 0.8 power factor to a condensive load? Compute the field current by (1) the general method (Potier triangle), (2) the synchronous-impedance method (A.I.E.E.), (3) the m.m.f. method.

139. Compute the retardation in revolutions per second per second as alternator A, C, E, or G drifts through synchronous speed (*a*) without field excitation, (*b*) with normal excitation on open circuit, (*c*) on short circuit with normal armature current, (*d*) when delivering its rated kilovolt-amperes at (1) unity power factor, (2) zero power factor. No mechanical power is supplied to the alternator.

140. Alternator A, C, E, or G supplies its normal current to a single-phase load at its normal line potential. Neglecting all losses and damping effects, determine the maximum swing of the rotor in electrical degrees from its mean position.

141. Two alternators of the same design are operating in parallel. The first delivers 980 kw. at 0.95 power factor, and the second, 720 kw. at 0.73 power factor. What adjustments should be made to have these alternators operate under the best conditions? When these have been made, what power will each deliver, and at what power factor will it operate?

142. Two 3-phase alternators, connected in parallel, are driven by shunt motors whose speed-load characteristics for particular field excitations are given by the following data: The speed of the first motor falls uniformly from 600 r.p.m. at no load to 530 r.p.m. at full load of 100 kw. on the alternator. The speed of the second motor falls uniformly from 590 r.p.m. at no load to 550 r.p.m. at full load of 100 kw. on the alternator. (*a*) For what load will the alternators divide the load equally? (*b*) What will be the load on each alternator when their combined load is 200 kw.? (*c*) What is the greatest load that can be delivered without overloading either alternator?

143. A 3-phase, 2200-volt alternator which is rated to deliver 760 kv.-a. is connected in parallel through transformers with a 3-phase, 5500-volt alternator which is rated to deliver 1500 kv.-a. The first alternator has 64 poles and is driven by an engine whose speed falls from 94 r.p.m. at no load to 91 r.p.m. at full load on the alternator. The second alternator has 72 poles and is driven by an engine whose speed falls from 83 r.p.m. at no load to 79 r.p.m. at full load on the alternator. (*a*) What is the greatest combined load that the alternators can deliver without overloading either by more than 25 per cent? (*b*) What is the load on each alternator when the first is running at 91.6 r.p.m.? (*c*) What is the frequency when they are delivering a combined load of 2000 kw.?

144. Two 3-phase, 60-cycle alternating-current generators are operating in parallel. The first has a capacity of 1000, and the second a capacity of 1500 kv.-a. The first is driven by a prime mover so adjusted that the frequency falls from 61 cycles at no load to 59.6 cycles at full load. The second has a different speed-load characteristic, the frequency falling from 61.4 cycles at no load to 59.2 cycles at full load.

When these alternators are jointly delivering 2000 kw., what is the load on each? What is the frequency? If the speed-load characteristic of the second is shifted parallel to itself until the alternators divide this load properly, what is the new value of the no-load frequency of this alternator? At what frequency will they now operate when delivering 2000 kw.?

145. Three 32,500-kv.-a. alternators operating in parallel are driven by water turbines whose governors are adjusted so that the speed falls 4 revolutions from no load to full load at unity power factor on the generators. These generators are delivering

a combined load of 75,000 kw. at normal frequency (150 r.p.m.) Two of the generators are each delivering 30,000 kw., the balance of the load being taken by the third generator. (*a*) If the third generator is disconnected from the line, what will be the per cent change in the frequency? (*b*) If the combined output is increased to 90,000 kw., how will it be divided between the generators? (*c*) If the combined output is reduced to 60,000 kw. and the first generator is disconnected from the line, how will the second and third generators divide the load between them?

146. Four alternators, three of 32,500- and one of 65,000-kv.-a capacity operating in parallel are driven by water turbines whose governors are so adjusted that the frequency of each of the smaller units will diminish by 0.6 cycle and of the larger unit by 0.4 cycle from no load to full load at unity power factor on the generators. These generators are delivering a combined load of 90,000 kw. at 24.6 cycles. This load is divided among the units so that the first delivers 15,000; the second, 25,000; the third 25,000; and the 65,000 kv.-a. unit, 15,000 kw. (*a*) If the 65,000-kv.-a. unit is disconnected from the line, how will the other 3 units divide the 90,000-kw. load? What will be the frequency? (*b*) If no adjustments are made, what is the greatest load that the 4 units can deliver without overloading any one?

147. Two 3-phase, 11,000-volt, 60-cycle alternating-current generators, operating in parallel, are driven by prime movers which have the same speed-load characteristic. The armature windings of the alternators are Y-connected and have an effective resistance of 0.94 ohm and a synchronous reactance of 36 ohms per phase. The total load supplied is 1700 kw. at 0.83 power factor. The excitations are adjusted so that the terminal potential is 11,000 volts and one of them is operating at unity power factor. What are the excitation e.m.fs. and the phase angle between them?

148. Two identical 3-phase, Y-connected alternators operating in parallel are driven by prime movers which have such dissimilar speed-load characteristics that when the first alternator is delivering 400 kw. at 0.8 power factor the second is running at no load. (*a*) If the excitations of the alternators are adjusted so that the terminal potential is 5000 volts and the armature current of the second alternator is zero, what are the excitation e.m.fs. and their phase displacement? (*b*) If the excitations are adjusted so that the terminal potential is 5000 volts and the

total armature copper loss is reduced to its least value, what current will each alternator deliver? The effective armature resistance and the synchronous reactance of each alternator are, respectively, 0.42 ohm and 12.4 ohms per phase.

149. Two identical 3-phase alternators, connected in parallel, are driven by prime movers which have dissimilar speed-load characteristics. When the excitations of the alternators are equal, the first delivers 100 amp. at 0.9 power factor (lagging), and the second, 75 amp. at 0.7 power factor (lagging). (*a*) What per cent of the total load does each alternator deliver? (*b*) What is the power factor of the load? (*c*) If the field excitations are adjusted so that both alternators operate at the same power factor, what current will each deliver? (*d*) If the field excitations are adjusted so that the total armature copper loss is reduced to its least value, at what power factor will each alternator operate?

150. Two identical 2-phase alternators, connected in parallel, are driven by prime movers which have somewhat dissimilar speed-load characteristics. The first alternator delivers 3200 kw. at 2210 volts and has an armature current of 760 amp., while the second delivers 3700 kw. at 2210 volts and has an armature current of 1100 amp. The effective armature resistance and the synchronous reactance of each alternator are, respectively, 0.0256 and 0.72 ohm per phase. The excitations of the alternators are now adjusted so as to reduce the total armature copper loss to its least value, but the terminal potential is maintained at 2210 volts. (*a*) At what power factor will each alternator be operating? (*b*) What is the reduction in the total armature copper loss? (*c*) What is the change in the copper loss of each alternator?

151. Two identical 3-phase alternators, operating in parallel on a balanced load, are driven by prime movers with different speed-load characteristics. The power output of each alternator is measured by two wattmeters. Show that when the differences between the wattmeter readings for each alternator are the same, the total armature copper loss is reduced to its least value for the given load.

152. Two dissimilar Y-connected alternators, operating in parallel, supply a load of 1500 kw. at 0.85 power factor and a terminal potential of 5000 volts. The alternators being of the same capacity are adjusted to deliver equal kilowatt loads.

The effective armature resistances are, respectively, 0.40 and 0.52 ohm per phase. What should be the armature current of each alternator in order that their combined armature copper loss will be reduced to its least value?

153. An alternator which has a capacity of 1650 kv.-a. is operated in parallel with one that has a capacity of 1000 kv.-a. Their armature resistances are 1.56 and 2.08 ohms, respectively. For a combined load of 2200 kw. at 0.83 power factor, what load should each deliver and at what power factor should it operate if the current and power outputs are proportional to their ratings? With this division of the kilowatt load, the excitations are adjusted so that the combined armature copper loss is reduced to a minimum. At what power factor should each alternator operate for this latter condition?

154. Two identical 12,000 kv.-a., 6600-volt, 60-cycle, 3-phase, Y-connected alternators, operating in parallel, supply an inductive load with 12,000 kw. at 0.90 power factor and a line potential of 6600 volts. The armatures of the alternators have an effective resistance of 0.04 ohm per phase. The open-circuit and zero-power-factor curves are given by the following data:

Field current	Terminal potential open circuit	Terminal potential zero power factor I_a = 1050 amperes
125	4,550	. .
175	5,900	0
212	6,600	1,400
275	7,450	3,720
355	8,050	5,630
425	8,350	6,600

The excitations of the alternators and the governors of the water turbines are so adjusted that the first alternator delivers 12,000 kw. and the second a lagging current of 508 amp. per terminal. At what power factor does each alternator operate? What is the field excitation of each alternator.

155. A number of alternators are operating in parallel at their rated frequency and terminal potential. One of these alternators delivers its rated kilovolt-amperes at 0.80 power factor (lagging). This alternator has a resistance of 1.5 per cent and a synchronous reactance of 60 per cent. The excitation of this alternator is

unaltered, but the proper adjustments are made so that its power output is increased 25 per cent and the frequency and terminal potential of the system are maintained constant. What adjustments are necessary to accomplish this? What is the per cent change in the kilovolt-ampere output of this alternator? At what power factor will it now operate?

156. Two 500-kv.-a., 3-phase, 240-volt alternators, operating in parallel, deliver equal kilovolt-amperes at the same power factor to an inductive load of 500 kw. at 0.85 power factor. Each alternator has an armature resistance of 0.0051 ohm between terminals, and the open-circuit and zero-power-factor characteristics are given by the following data:

Field current	Terminal potential open circuit	Terminal potential zero power factor $I_a = 1{,}200$
48	175	0
60	215	43
72	240	86
90	270	147
114	300	204
130	. . .	232
140	. .	245
150		257

The excitation of one alternator is unchanged, but the power is cut off from its prime mover. The excitation of the other alternator is automatically adjusted by a regulator so that the line potential is maintained constant. What current does the first alternator deliver, and what is the field excitation of the second?

157. Two identical 3-phase, Y-connected alternators are operating in parallel at a terminal potential of 2200 volts. The effective armature resistance and the synchronous reactance of these alternators are, respectively, 0.158 ohm and 2.12 ohms per phase. The characteristics of the prime movers are so dissimilar that of the total load of 1500 kw. at 0.85 power factor the first alternator supplies 840 kw. The excitations of the alternators are adjusted so that both are operating at the same power factor. What are their excitation e.m.fs. and the phase displacement between them?

158. Two identical 3-phase, Y-connected alternators, operating in parallel, are driven by prime movers which have identical speed-load characteristics. The effective armature resistance and the synchronous reactance of the alternators are, respectively, 2.18 and 62 ohms per phase.

The alternators supply 1830 kw. at 13,800 volts to an induction motor load which is operating at 0.83 power factor. The excitations of the alternators are adjusted so that the first supplies a current of 40 amp., lagging. (*a*) What current does the second alternator supply? (*b*) What are the excitation e.m.fs. of the alternators and their phase displacement?

159. Two identical 3-phase, Y-connected alternators, operating in parallel, are driven by prime movers which have the same speed-load characteristic. The alternators are rated to deliver 1000 kv.-a. at 2400 volts. The effective armature resistance and the synchronous reactance are, respectively, 0.067 ohm and 2.64 ohms per phase. Assume that the rotational losses, both core loss and friction, are constant and equal. (*a*) If these alternators are delivering 2000 kw. at unity power factor and their rated potential, by what amount can the load be shifted from one to the other if their field excitations are adjusted so that there is an interchange component of current equal to the full-load current, *viz.*, 240 amp.? (*b*) If these alternators are delivering 1500 kw. at 0.75 power factor and their rated potential, by what amount can the load be shifted from one to the other if their field excitations are adjusted so that there is an interchange component of current equal to the full-load current, *viz.*, 240 amp.

160. The alternators described in problem 159 are operating in parallel with non-inductive resistances of 0.8 inserted in each phase of each alternator. (*a*) If the alternators are jointly delivering 2000 kw. at unity power factor and their rated potential to a load, by what amount can this load be shifted from one to the other if the excitations are adjusted so that there is an interchange component of current equal to the full-load current, *viz.*, 240 amp.? (*b*) If the alternators are jointly delivering 1500 kw. at 0.75 power factor and their rated potential to a load, by what amount can this load be shifted from one to the other if the excitations are adjusted so that there is an interchange component of current equal to the full-load current, *viz.*, 240 amp.?

161. Two identical 3-phase alternators, rigidly coupled together so that their excitation e.m.fs. are in phase, are driven by a shunt motor. The effective armature resistance and the synchronous reactance of each alternator are, respectively, 0.302 ohm and 4.36 ohms per phase. The terminals of the alternators are electrically connected as they would be for parallel operation, but no external load is supplied. When the field excitations are adjusted so that the excitation e.m.fs. are, respectively, 200 and 300 volts per phase, what is the armature current? If the armature windings are connected in Δ, what is the terminal potential? What is the electrical output of the alternator which is acting as a generator? If the rotational losses are supplied by the shunt motor, what is the mechanical output of the alternator which is acting as a motor? If the rotational losses are 1620 watts, what power does the shunt motor supply?

162. If the alternators described in problem 161 are mechanically coupled together so that their excitation e.m.fs. differ in phase by 30 deg., what will be the armature current when the excitation e.m.fs. are each 300 volts? What is their terminal potential? What is the electrical output of the alternator which is acting as a generator? If the rotational losses are supplied by the shunt motor, what is the mechanical output of the alternator which is acting as a motor? What power does the shunt motor supply if the rotational losses are 1620 watts?

163. Two identical, Y-connected, 60-cycle alternators are rigidly coupled together and are driven at their rated speed of 1200 r.p.m. The alternators have revolving fields, and the coupling is so made that the north poles of the first are 10 deg. (mechanical) ahead, *i.e.*, in the direction of rotation, of the corresponding north poles of the second. The corresponding terminals are connected through non-inductive resistances of 1.5 ohms each. The effective armature resistance and the synchronous reactance of each alternator are, respectively, 0.302 ohm and 4.36 ohms per phase. The field currents are adjusted so that the excitation e.m.fs. are, respectively, 200 and 300 volts per phase. What is the current? What is the electrical output of the alternator which is acting as a generator? If the rotational losses are supplied by the driving motor, what is the mechanical output of the alternator which is acting as a motor? If the rotational losses are 1620 watts, what is the output of the driving motor?

164. Two identical, 3-phase, Y-connected alternators, rigidly coupled to the same prime mover, are operating in parallel and supply 1500 kw. at 0.83 power factor and a terminal potential of 5000 volts. The effective armature resistance and the synchronous reactance of each alternator are, respectively, 0.42 ohm and 12.4 ohms per phase. The mechanical coupling is so made that the excitation e m.fs. are in phase, and the field currents are adjusted so that one of these e.m.fs. is 50 per cent greater than the other. What is the output of each alternator?

165. Two 3-phase, Y-connected alternators, each of which is rated to deliver 760 kv.-a. at 2200 volts, are rigidly coupled to the same prime mover. Each of these alternators has 64 field poles, an effective armature resistance of 0.172 ohm, and a synchronous reactance of 2.12 ohms per phase. With equal field excitations, they operate at full load with undue heating; and, on examination, it is found that their corresponding field poles are displaced by an angle of 1 deg 6 min. (*a*) When they deliver 1500 kw. at 0 87 power factor and their rated potential, what is the output of each alternator if the field excitations are equal? (*b*) If this displacement of the field poles is reduced to zero, what will be the reduction in the armature copper loss of each alternator? The load delivered is still 1500 kw. at 0.87 power factor and their rated potential.

166. Two identical, 2-phase, 3750-kv.-a. waterwheel generators, operating in parallel, are driven by prime movers which have the same speed-load characteristic. The effective armature resistance and the synchronous reactance of these alternators are, respectively, 0.0254 ohm and 1.12 ohms per phase. The alternators are jointly delivering 7500 kw. at unity power factor and their rated terminal potential of 2200 volts. The excitations are equal.

Instantaneous records show that, due to hunting, the maximum displacement of their excitation e.m.fs. is 30 deg. What is the synchronizing power at the time of maximum displacement? What is the maximum value of the effective armature current?

167. If the alternators described in problem 166 are jointly delivering 5250 kw. at 0.7 power factor and their rated potential to an inductive load, what is the synchronizing power at the time the displacement of their excitation e.m.fs. is 30 deg.? What are the effective armature currents at this time?

168. If the alternators described in problem 166 are jointly delivering 5250 kw. at 0.7 power factor and their rated potential to a condensive load, what is the synchronizing power at the time the displacement of their excitation e.m.fs. is 30 deg.? What are the effective armature currents at this time?

169. Two identical 3-phase, Y-connected alternators, each of which is rated to deliver 1640 kv.-a. at 13,500 volts, are operating in parallel. The speed-load characteristics of the prime movers are the same, and the load requires 70 amp. from each alternator at 0.83 power factor and the rated potential. The effective armature resistance and the synchronous reactance of the alternators are, respectively, 1.52 and 37.4 ohms per phase. Oscillograph records show that, due to hunting, the greatest value of the effective armature current is 87 amp. What is the maximum displacement between the excitation e.m.fs.? What is the synchronizing power at this maximum displacement?

170. Two alternators of the same design (see the design of A, . . . D, . . . or H), operating in parallel, deliver their combined rated kilovolt-amperes at (*a*) unity power factor, (*b*) 0.8 power factor to an inductive load, (*c*) 0.8 power factor to a capacitive load. The excitations of the alternators are equal and are adjusted so that the terminal potential has its rated value. The rotors are displaced relatively by an electrical angle of 20 deg. What are the kilowatt and kilovolt-ampere output of each alternator? Use the A.I.E.E. method of computation.

171. Two alternators of the same design (use the design of A, . . . D, or H), operating in parallel, deliver their combined rated kilovolt-amperes at (*a*) unity power factor, (*b*) 0.8 power factor to an inductive load, (*c*) 0.8 power factor to a condensive load. The excitation e.m.fs. are in phase, but one is 20 per cent greater than the other. The terminal potential has its rated value. What are the kilowatt and kilovolt-ampere output of each alternator? Use the A.I.E.E. method of computation.

172. A number of alternators are operating in parallel at their rated frequency and terminal potential. One of these alternators has a resistance of 1.0 per cent and a synchronous reactance of 50 per cent. When this alternator is delivering its rated kilovolt-amperes at (*a*) unity power factor, (*b*) 0.8 power factor (lagging), (*c*) 0.8 power factor (leading), the power is

cut off from its prime mover, but the field excitation is unaltered. The line potential is maintained constant by regulators acting on the other alternators. What per cent of its rated kilovolt-amperes does this alternator now deliver?

173. A number of alternators are operating in parallel at their rated frequency and terminal potential. One of these alternators is A, . . . D, . . . or H. When this alternator is delivering its rated kilovolt-amperes at (*a*) unity power factor, (*b*) 0.8 power factor (lagging), (*c*) 0.8 power factor (leading), the power is cut off from its prime mover, but the field excitation is unaltered. The line potential is maintained constant by regulators acting on the other alternators. What per cent of its rated kilovolt-amperes does this alternator now deliver?

174. A number of alternators are operating in parallel at their rated frequency and terminal potential. One of these alternators has a resistance of 0.5 per cent and a synchronous reactance of 40 per cent. When this alternator is delivering its rated kilovolt-amperes at zero power factor (*a*) lagging, (*b*) leading, it looses its field excitation. The line potential is maintained constant by regulators acting on the other alternators. What per cent of its rated kilovolt-amperes does this alternator now deliver?

175. A number of alternators are operating in parallel at their rated frequency and terminal potential. One of these alternators is A, . . . D, . . . or H. When this alternator is delivering its rated kilovolt-amperes at (*a*) unity power factor, (*b*) 0.8 power factor (lagging), (*c*) 0.8 power factor (leading), the power is cut off from its prime mover, but the field excitation is unaltered. The line potential is maintained constant by regulators acting on the other alternators. What per cent of its rated kilovolt-amperes does this alternator now deliver?

176. A number of alternators are operating in parallel at their rated frequency and terminal potential. One of these alternators has a resistance of 0.7 per cent and a synchronous reactance of 45 per cent. This alternator is delivering power (kilowatts) equal to 80 per cent of its rated kilovolt-amperes. If the excitation e.m.f. is (*a*) normal, (*b*) 10 per cent greater than normal, (*c*) 10 per cent less than normal, what is the kilovolt-ampere output of the alternator?

177. A number of alternators are operating in parallel at their rated frequency and terminal potential. One of these alternators is A, . . . D, . . . or H. This alternator is

delivering power (kilowatts) equal to 90 per cent of its rated kilovolt-amperes. If the excitation e.m.f. is (*a*) normal, (*b*) 10 per cent greater than normal, (*c*) 10 per cent less than normal, what is the kilovolt-ampere output of the alternator?

178. A number of alternators are operating in parallel at their rated frequency and terminal potential. One of these alternators has a resistance of 0.6 per cent and a synchronous reactance of 50 per cent. This alternator is delivering power (kilowatts) equal to 80 per cent of its rated kilovolt-amperes. When the excitation e.m.f. is (*a*) normal, (*b*) 10 per cent greater than normal, (*c*) 10 per cent less than normal, what will be the per cent change both in the kilowatt and kilovolt-ampere output of this alternator if the angle between the excitation e.m.f. and the terminal potential is (1) increased 50 per cent, (2) reduced 50 per cent? Assume that the frequency and terminal potential are maintained constant.

179. A number of alternators are operating in parallel at their rated frequency and terminal potential. One of these alternators is A, . . . D, . . or H. This alternator is delivering power (kilowatts) equal to 80 per cent of its rated kilovolt-amperes When the excitation e.m.f. is (*a*) normal, (*b*) 10 per cent greater than normal, (*c*) 10 per cent less than normal, what will be the per cent change both in the kilowatt and kilovolt-ampere output of this alternator if the angle between the excitation e.m.f. and the terminal potential is (1) increased 50 per cent, (2) reduced 50 per cent? Assume that the frequency and terminal potential are maintained constant.

180. A number of alternators are operating in parallel at their rated frequency and terminal potential. One of these alternators has a resistance of 0.5 per cent and a synchronous reactance of 60 per cent. This alternator is delivering power (kilowatts) equal to 80 per cent of its kilovolt-ampere rating, and the excitation e.m.f. is 10 per cent greater than normal. What will be the per cent change both in the reactive kilovolt-amperes delivered and in the phase angle between the excitation e.m.f. and the terminal potential produced by (*a*) an increase in the excitation e.m.f. to 120 per cent of its normal value, (*b*) a decrease in the excitation e.m.f. to 100 per cent of its normal value?

181. A number of alternators are operating in parallel at their rated frequency and terminal potential. One of these alternators is A, . D, . or H. This alternator is

delivering power (kilowatts) equal to 80 per cent of its kilovolt-ampere rating, and the excitation e.m.f. is 10 per cent greater than normal. What will be the per cent change both in the reactive kilovolt-amperes delivered and in the phase angle between the excitation e.m.f. and the terminal potential produced by (*a*) an increase in the excitation e.m.f. to 120 per cent of its normal value, (*b*) a decrease in the excitation e.m.f. to 100 per cent of its normal value?

182. A number of alternators are operating in parallel at their rated frequency and terminal potential. One of these alternators has a resistance of 0.5 per cent and a synchronous reactance of 50 per cent. When this alternator has an excitation e.m.f. equal to (*a*) its normal value, (*b*) 120 per cent of its normal value, (*c*) 80 per cent of its normal value and the excitation e.m.f. is (1) in phase with the terminal potential, (2) leads the terminal potential by 15 deg., (3) leads the terminal potential by 30 degrees, what is the output of the alternator?

183. A number of alternators are operating in parallel at their rated frequency and terminal potential. One of these alternators is A, . . . D, . . . or H. When this alternator has an excitation e.m.f. equal to (*a*) its normal value, (*b*) 120 per cent of its normal value, (*c*) 80 per cent of its normal value and the excitation e.m.f. is (1) in phase with the terminal potential (2) leads the terminal potential by 15 deg., (3) leads the terminal potential by 30 deg, what is the output of the alternator?

184. A number of alternators are operating in parallel at their rated frequency and line potential. One of these alternators has a resistance of 0.5 per cent and a synchronous reactance of 55 per cent. This alternator is delivering power (kilowatts) equal to 80 per cent of its rated kilovolt-amperes. The excitation e.m.f. is equal to (*a*) its normal value, (*b*) 125 per cent of its normal value, (*c*) 90 per cent of its normal value. Due to a short circuit in the field-circuit rheostat, the excitation e.m.f. increases to (1) 140 per cent of its normal value, (2) 160 per cent of its normal value. Assume that the increase in the excitation e.m.f. is so rapid that the speed of the alternator does not change until the e.m.f. has become constant. What is the output of the alternator after the excitation e.m.f. has increased and before the speed has changed? What is the phase swing in the excitation e.m.f. by the time that equilibrium has again been established?

185. A number of alternators are operating in parallel at their rated frequency and line potential. One of these alternators is A, . . . D, . . or H. This alternator is delivering power (kilowatts) equal to 80 per cent of its rated kilovolt-amperes. The excitation e.m.f. is equal to (*a*) its normal value, (*b*) 125 per cent of its normal value, (*c*) 90 per cent of its normal value. Due to a short circuit in the field-circuit rheostat, the excitation e.m.f. increases to (1) 140 per cent of its normal value, (2) 160 per cent of its normal value. Assume that the increase in the excitation e.m.f. is so rapid that the speed of the alternator does not change until the e.m.f. has become constant. What is the output of the alternator after the excitation e.m.f. has increased and before the speed has changed? What is the phase swing in the excitation e.m.f. by the time that equilibrium has again been established?

186. A number of alternators are operating in parallel at their rated frequency and terminal potential. One of these alternators has a resistance of 1.0 per cent, a synchronous reactance of 50 per cent at an internal power factor of zero, and a synchronous resistance of 30 per cent at an internal power factor of unity. When this alternator is delivering its rated kilovolt-amperes at (*a*) unity power factor, (*b*) 0.8 power factor (lagging), (*c*) 0.8 power factor (leading), the power is cut off from its prime mover, but the field excitation is unaltered. The line potential is maintained constant by regulators acting on the other alternators. What per cent of its rated kilovolt-amperes does this alternator now deliver?

187. A number of alternators are operating in parallel at their rated frequency and terminal potential. One of these alternators has a resistance of 0.5 per cent, a synchronous reactance of 40 per cent at an internal power factor of zero and a synchronous reactance of 25 per cent at an internal power factor of unity. When this alternator is delivering its rated kilovolt-amperes at zero power factor (*a*) lagging, (*b*) leading, it loses its field excitation. The line potential is maintained constant by regulators acting on the other alternators. What per cent of its rated kilovolt-amperes does this alternator now deliver?

188. A number of alternators are operating in parallel at their rated frequency and terminal potential. One of these alternators has a resistance of 0.7 per cent, a synchronous reactance of 45 per cent at an internal power factor of zero, and

a synchronous resistance of 30 per cent at an internal power factor of unity. This alternator is delivering power (kilowatts) equal to 80 per cent of its rated kilovolt-amperes. If the excitation e.m.f. is (*a*) normal, (*b*) 10 per cent greater than normal, (*c*) 10 per cent less than normal, what is the kilovolt-ampere output of the alternator?

189. A number of alternators are operating in parallel at their rated frequency and terminal potential. One of these alternators has a resistance of 0.6 per cent, a synchronous reactance of 50 per cent at an internal power factor of zero, and a synchronous resistance of 32 per cent at an internal power factor of unity. This alternator is delivering power (kilowatts) equal to 80 per cent of its rated kilovolt-amperes. When the excitation e.m.f. is (*a*) normal, (*b*) 10 per cent greater than normal, (*c*) 10 per cent less than normal, what will be the per cent change both in the kilowatt and kilovolt-ampere output of this alternator if the angle between the excitation e.m.f. and the terminal potential is (1) increased 50 per cent, (2) reduced 50 per cent. Assume that the frequency and terminal potential are maintained constant.

190. A number of alternators are operating in parallel at their rated frequency and terminal potential. One of these alternators has a resistance of 0.5 per cent, a synchronous reactance of 60 per cent at an internal power factor of zero, and a synchronous resistance of 40 per cent at an internal power factor of unity. This alternator is delivering power (kilowatts) equal to 80 per cent of its kilovolt-ampere rating, and the excitation e.m.f. is 10 per cent greater than normal. What will be the per cent change both in the reactive kilovolt-amperes delivered and in the phase angle between the excitation e.m.f. and the terminal potential produced by (*a*) an increase in the excitation e.m.f. to 120 per cent of its normal value, (*b*) a decrease in the excitation e.m.f. to 100 per cent of its normal value?

191. A number of alternators are operating in parallel at their rated frequency and terminal potential. One of these alternators has a resistance of 0.5 per cent, a synchronous reactance of 50 per cent at an internal power factor of zero, and a synchronous resistance of 32 per cent at an internal power factor of unity. When this alternator has an excitation e.m.f. equal to (*a*) its normal value, (*b*) 120 per cent of its normal value, (*c*) 80 per cent of its normal value and the excitation

e.m.f. is (1) in phase with the terminal potential, (2) leads the terminal potential by 15 deg., (3) leads the terminal potential by 30 deg., what is its output?

192. A number of alternators are operating in parallel at their rated frequency and line potential. One of these alternators has a resistance of 0.5 per cent, a synchronous reactance of 55 per cent at an internal power factor of zero, and a synchronous reactance of 35 per cent at an internal power factor of unity. This alternator is delivering power (kilowatts) equal to 80 per cent of its rated kilovolt-amperes. The excitation e.m.f. is equal to (*a*) its normal value, (*b*) 125 per cent of its normal value, (*c*) 90 per cent of its normal value. Due to a short circuit in the field-circuit rheostat, the excitation e.m.f. increases to (1) 140 per cent of its normal value, (2) 160 per cent of its normal value. Assume that the increase in the excitation e.m.f. is so rapid that the speed of the alternator does not change until the e.m.f. has become constant. What is the output of the alternator after the excitation e.m.f. has increased and before the speed has changed? What is the phase swing in the excitation e.m.f. by the time that equilibrium has again been established?

193. A 1500-kw., 5500-volt, 3-phase generator delivers power to a transmission line through three single-phase transformers which have their low-tension windings connected in delta and their high-tension windings connected in Y. The following data on this generator and the transformers are given:

Generator

Field current	Open-circuit terminal potential	Short-circuit armature current
150	5,100	300
200	5,900	400
250	6,500	
300	6,800	
350	7,100	

The core loss at the rated potential is 20.2 kw., and the friction and windage is 8.4 kw. Both of these losses may be assumed constant. The effective resistance of the armature is 0.362 ohm per phase. The resistance of the field winding is 0.376 ohm. The armature windings are connected in Y.

TRANSFORMER

Kilovolt-amperes	Potential		Short circuit		
	High tension	Low tension	Amperes[1]	Volts	Watts
500	12,700	5,500	39 4	332	4,680

[1] Full-load current

The core loss at the rated potential is 3330 watts and may be assumed constant. (*a*) When the power delivered to the transmission line is 1280 kw. at a power factor of 0.83 and a line potential of 22,300 volts, what is the combined efficiency of the generator and transformers? Calculate the generator field current by the m.m.f. method. (*b*) If this load is removed from the line and the field excitation of the generator is unchanged what is the high-tension line potential?

194. A 1640-kw., 13,500-volt, 3-phase generator delivers power to a transmission line through three single-phase transformers which are connected in Y on both the high- and low-tension sides. The following data are given on this generator and transformers:

GENERATOR

Field current	Open-circuit terminal potential	Short-circuit armature current
50	7,500	75
100	10,100	155
150	14,700	227
200	15,800	
250	16,700	

The core loss at the rated potential is 21.3 kw., and the friction and windage is 8.8 kw. Both of these losses may be assumed constant. The effective resistance of the armature is 1.52 ohms per phase. The resistance of the field circuit is 0.392 ohm. The armature windings are connected in Y.

TRANSFORMERS

Kilovolt-amperes	Potential		Short circuit		
	High tension	Low tension	Amperes[1]	Volts	Watts
500	38,000	7,800	13.15	1,190	3,375

[1] Full-load current.

The core loss at the rated potential is 2960 watts and may be assumed constant. (*a*) When the output of the generator is 1460 kw. at 0.92 power factor and a terminal potential of 13,600 volts, what is the combined efficiency of the generator and transformers? Calculate the field current of the generator by the m.m.f. method. (*b*) If this load is removed from the line and the field excitation of the generator is unchanged, what is the high-tension line potential?

195. A 1000-kw., 2400-volt, 3-phase generator delivers power to a transmission line through three single-phase transformers which are connected in Δ on the low-tension and in Y on the high-tension side. Each transformer has a ratio of transformation of 5.29:1. The resistances of the high- and low-tension windings are 2.02 ohms and 0.072 ohm, respectively. The effective resistance of the generator is 0.067 ohm per phase. The armature windings are connected in Y. With the high-tension windings of the transformers short circuited and with a field excitation of 100 amp. for the generator, the armature current is 458 amp. With this same excitation, the open-circuit terminal potential of the generator is 2220 volts. The rotation losses in the generator are 31.2 kw. at normal potential, and the core losses in each transformer are 1.8 kw. (*a*) What is the combined efficiency of the generator armature and the transformers when a balanced load of 954 kw. at 0.91 power factor is delivered on the high-tension side of the transformers at a line potential of 22,400 volts? (*b*) What would be the high-tension line potential if this load were removed and the excitation of the generator unchanged?

196. A 760-kw., 2200-volt, 3-phase generator delivers power to a transmission line through three single-phase transformers which have both their high- and low-tension windings connected in Y. With the high-tension windings of the transformers

short circuited, the output of the generator is 37.8 kw., and the armature current is 450 amp. when the terminal potential is 133 volts. With the transformers on open circuit and with the same field excitation, the terminal potential of the generator is 1780 volts. The effective resistance of the armature is 0.172 ohm per phase. The armature windings are connected in Y. The rotation losses of the generator are 17.2 kw. at normal potential, and the core loss in each transformer is 1670 watts. The transformers have a ratio of transformation of 10:1. (*a*) What is the combined efficiency of the generator armature and the transformers when a balanced load of 680 kw. at 0.9 power factor is delivered to the transmission line at 22,400 volts? (*b*) What would be the high-tension line potential if this load were removed and the excitation of the generator unchanged?

197. A 1000-kw., 11,000-volt, 3-phase generator delivers power to a transmission line at the end of which is a 1200-hp. induction motor. With the induction motor running at no load, the excitation of the generator is adjusted so that the terminal potential, the line current, and the total power measured at the motor are 10,600 volts, 20.2 amp., and 20.4 kw., respectively. At the same time, the terminal potential and the total power measured at the generator are 10,980 volts and 29.8 kw. The field excitation of the generator is now adjusted so that, when the motor is delivering full load, the terminal potential at the motor is 11,000 volts. The efficiency and power factor of the motor at full load are 0.921 and 0.906, respectively.

What is the terminal potential of the generator when the motor delivers full load? What is the efficiency of transmission at this time?

198. A 1000-kw., 13,800-volt, 3-phase, Y-connected generator delivers power directly to a transmission line at the end of which is an induction motor load. The resistance and reactance of the transmission line are 16.8 and 17.2 ohms per conductor. The generator has an effective armature resistance of 2.18 ohms per phase. The field current is supplied at 120 volts.

Field current	Open-circuit terminal potential	Terminal potential with an armature current of 42 amperes at zero power factor
50	8,800	
80	13,000	
110	15,600	10,750
140	17,250	13,250
180	18,900	15,600

On open circuit, the rotational losses are 16.6 and 25.4 kw. when the terminal potentials are 13,000 and 15,600 volts, respectively.

What should be the field excitation of the generator so that the line potential at the motor load will be 13,200 volts when the motors take 926 kw at 0.91 power factor? What is the efficiency of the generator and the line?

199. A 1640-kv.-a., 13,500-volt, 3-phase generator delivers power directly to a transmission line which has a resistance of 30.2 ohms and a reactance of 24 ohms per conductor. With the far end of the line short circuited and with a field excitation of 150 amp., the line current is 138 amp. With the same field excitation, the open-circuit terminal potential of the generator is 14,700 volts. The effective resistance of the armature is 1.52 ohms per phase. The generator is Y-connected.

What is the combined electrical efficiency of the armature of the generator and the transmission line for a load of 1500 kw. at 0.90 power factor if the line potential at the load is 13,200 volts? To what value will the line potential rise if this load is removed and the field excitation of the generator is unchanged?

200. A 1000-kv.-a , 11,000-volt, 3-phase generator delivers power directly to a transmission line which has a resistance of 8.42 and a reactance of 6.8 ohms per conductor.

Field current	Open-circuit terminal potential	Rotational losses
20	8,400	11,600
30	11,000	19,400
40	12,700	25,600
50	13,800	
60	14,700	
70	15,500	

The armature has an effective resistance of 0.94 ohm per phase, and the windings are connected in Y. The field current is supplied at 260 volts. With the far end of the line short circuited and with a field current of 40 amp., the line current is 115 amp. If the load at the end of the line requires 940 kw. at 0.92 power factor, what must be the excitation of the generator in order that the line potential at the load shall be 11,000 volts?

201. A 1000-kw., 13,800-volt, 3-phase alternating-current generator delivers power over a transmission line to a synchronous motor load. The resistance and reactance of the line are 16.5 and 17.1 ohms per conductor, respectively. The armature of the generator has an effective resistance of 2.18 ohms per phase. The field current is supplied at 120 volts.

Field current	Open-circuit terminal potential[1]	Core loss at open circuit kilowatts
50	8,800	7.5
80	13,000	16.6
110	15,600	25.4
140	17,250	33.5
180	18,900	

[1] The armature windings are Y-connected.

With the synchronous motor running at no load and with under-excitation, the line current has its full-load value of 42 amp., the line potential at the motor is 13,200 volts, and the power supplied to the motor is 28.6 kw. At this time, the field excitation of the generator is 161 amp.

When the motor load requires 1000 kw., what must be the excitation of the generator in order that it shall operate at unity power factor[1] and the line potential at the load shall be 13,200 volts? What is the power factor of the load?

202. A 3500-kw., 10,000-volt, 2-phase alternating-current generator delivers power through Scott transformers to a 3-phase transmission line. With the far end of this line short circuited, the output of the generator is 490 kw., and the armature current and terminal potential are 220 amp. and 1630 volts. On open

[1] The excitation of the motor must also be properly adjusted for this to occur.

circuit, the high-tension line potential is 33,000 volts when the terminal potential of the generator is 10,000 volts. The armature has an effective resistance of 0.64 ohm per phase. The open- and short-circuit characteristics are

Field current	Open-circuit terminal potential	Short-circuit armature current
100	7,700	220
200	10,200	430
250	10,900	
300	11,500	
375	12,200	

If there is a load requiring 3200 kw. at 0.91 power factor at the end of the line, what must be the excitation of the generator in order that the line potential at the load shall be 30,000 volts? Use the m.m.f. method when dealing with the generator.

203. A 1500-kv.-a., 5500-volt alternator delivers energy to a high-tension transmission line through step-up transformers the low-tension windings of which are connected in Δ, and the high-tension windings in Y. The neutrals of the generator and of the high-tension transformer windings are grounded. The transformers hav a ratio of transformation of 6.3:1.0.

Generator Characteristics

Field current	Terminal potential on open circuit	Armature current on short circuit
100	3,500	200
150	5,100	300
200	5,900	400
250	6,500	
300	6,800	
350	7,100	

The effective resistance of the armature is 0.36 ohm per phase. The resistance of the field circuit is 0.386 ohm. The power required to drive the generator on open circuit with a terminal potential of 5500 volts is 28.6 kw.

TRANSFORMER CHARACTERISTICS

With the high-tension winding short circuited and 170 volts impressed on the low-tension winding, the current supplied to a transformer is 91 amp., and the power is 4.26 kw. At no load and with 5500 volts impressed on the low-tension winding, the power is 3.12 kw.

With a balanced load of 1360 kw. at 0.83 power factor delivered to the high-tension line at 60,000 volts, what must be the generator's excitation? What is the combined efficiency of the generator and the transformer at this load? If this load were removed, what would be the high-tension line potential if the excitation of the generator were unchanged? Use (*a*) the synchronous-impedance method, (*b*) the m.m.f. method when calculating the field current of the generator.

204. A 1000-kv.-a., 2400-volt alternator delivers energy to a high-tension transmission line through step-up transformers, both the low- and high-tension windings of which are connected in Y. The armature windings of the generator, which are connected in Δ, have an effective resistance of 0.20 ohm per phase. The resistance of the field circuit is 0.427 ohm. The friction and windage loss is 8.2 kw.

GENERATOR CHARACTERISTICS

Field current	Open-circuit terminal potential	Terminal potential, I_a = 139, power factor = 0	Core loss on open circuit kilowatts
60	1,470		7 6
100	2,220		17 9
140	2,700	1,920	28 5
180	2,980	2,370	37.0
220	3,180	2,630	

TRANSFORMER CHARACTERISTICS

The transformers have a ratio of transformation of 1390:12,700 volts. With the low-tension winding short circuited and with 332 volts impressed on the high-tension winding, the current is 26.2 amp., and the power is 3120 watts. The core loss at the rated potential is 2220 watts.

The heaviest load that the high-tension line requires is 1000 kw. at 0.88 power factor, and the necessary line potential is 24,500 volts. What must be the terminal potential of the generator exciter for this load? What is the combined efficiency of the generator and the transformers at this load?

205. A 1500-kv.-a., 5500-volt alternator delivers energy to a high-tension transmission line through 3 step-up transformers, the low-tension windings of which are connected in Δ and the high-tension windings in Y. The neutrals of the generator and of the high-tension transformer windings are grounded. The transformers have a ratio of transformation of 3.2:1.0. The calculated resistance and reactance of the high-tension line are 48.6 and 59.4 ohms per conductor, respectively. The generator has an effective armature resistance of 0.36 ohm per phase. The open- and short-circuit characteristic data for the generator are

Field current	Terminal potential on open circuit	Armature current on short circuit
100	3,500	200
150	5,100	300
200	5,900	
250	6,500	
300	6,800	
350	7,100	

With the far end of the transmission line short circuited, the generator supplies a current of 165 amp. at a terminal potential of 860 volts, and the power delivered to the transformers and line is 146 kw.

If, when the far end of this transmission line delivers a balanced load of 1450 kw. at a power factor of 0.93, the line potential at the load is 30,000 volts, to what value would this potential rise if the load were removed? Use what you consider the most exact method of calculation.

206. A 1000-kv.-a., 13,800-volt generator delivers power over a transmission line and through step-down transformers which are connected in Δ on both the high- and low-tension sides. The armature windings of the generator, which are

connected in Y, have an effective resistance of 2.18 ohms per phase. The resistance of the field circuit is 0.541 ohm.

GENERATOR CHARACTERISTICS

Field current	Terminal potential on open circuit	Terminal potential, $I_a = 42$, $PF = 0$	Core loss on open circuit kilowatts
50	8,800		7 5
80	13,000		16 6
110	15,600	10,750	25 4
140	17,250	13,250	33 5
180	18,900	15,600	

The friction and windage loss is 7.9 kw.

TRANSFORMER CHARACTERISTICS

Each transformer has a ratio of transformation of 425:13,200 volts. With the low-tension windings short circuited and with 1100 volts impressed on the high-tension winding, the current is 25.2 amp. and the power is 3070 watts. The core loss at the rated potential is 2130 watts.

The calculated resistance and reactance of the transmission line are 15.7 and 16.2 ohms per conductor.

With the low-tension windings of the transformers short circuited, what must be the terminal potential of the generator in order that it will deliver its full-load current? When the transformers deliver a load of 1000 kv.-a. at 0.90 power factor and a line potential of 420 volts, what is the necessary excitation of the generator, and what is the combined efficiency of the generator, line, and transformers?

207. An 850-kv.-a., 11,000-volt, Y-connected generator delivers energy over a transmission line and through transformers, which are connected in Y on the high-tension and in Δ on the low-tension sides, to a load of induction motors and a synchronous motor. The resistance and reactance of the line are 11.4 and 10.6 ohms per conductor, respectively. The transformers are each rated to deliver 300 kw. with a ratio of transformation of 6600:660 volts.

GENERATOR CHARACTERISTICS

Field current	Open-circuit phase potential	Short-circuit armature current
25	2,200	72
50	4,070	
75	5,500	
100	6,270	
125	6,930	
150	7,370	
175	7,700	

The ohmic resistance of the armature between terminals is 3.32 ohms at the running temperature. The effective resistance is 1.45 times the ohmic resistance. The field resistance is 0.723 ohm. The core and friction losses are 26 kw. at the rated potential.

TRANSFORMER CHARACTERISTICS

With the low-tension winding short circuited and with 240 volts impressed on the high-tension winding, the current is 47 amp., and the power, 2.8 kw. The core loss at the rated potential is 2.6 kw.

The induction motors take a constant load of 220 kw. at 0.83 power factor. The synchronous motor takes a constant load of 460 kw., and, with the greatest allowable field excitation, its line current is 610 amp., and the terminal potential is raised to 650 volts.

Calculate the terminal potential of the generator exciter, and the combined efficiency of the generator, line, and transformers.

Use what you consider the most exact method.

NOTE I.—In calculating the armature reaction, it is recommended to use $0.707k\ NI/P$ for turboalternators and $0.75k\ NI/P$ for salient-pole machines. k is the total reduction factor for breadth and pitch, and NI/P represents the armature ampere-turns per pole.

NOTE II.—See LAWRENCE, R. R., "Principles of Alternating Current Machinery," pp. 106–115. If not given assume that the ratio of pole arc to pole pitch is 0.75.

Synchronous Generator Data

Number	A	B	C	D	E	F	G	H
Kilovolt-amperes	1 000	6 250	8,000	8 750	12,550	16,000	17 000	35,300
Volts	2,300	2,400	6 600	11 000	14,000	11,000	6 600	13,800
Cycles	60	60	60	25	60	60	50	60
Connection	Y	2-circuit Y	Y	Y	Y	3-circuit Y	Y	2-circuit Y
Poles	48	2	64	14	72	54	16	4
Turns per pole	43 5	92 5	32 5	120 5	37 5	41 5	115 5	102 5
Diameter at air gap, inches	96	28	177	115	260	218	135	54
Length of core, inches	12	66	35	36	27	34	30	110
Number of slots	270	54	288	192	378	324	216	60
Series conductors per slot	6	2	6	6	6	10	2	6
Coil pitch, slots	4	16	4	11	4	6	12	11
Armature resistance per phase	0 089	0 0026	0 087	0 0945	0 085	0 04	0 00985	0 00985
at temperature, degrees centigrade	25	75	25	75	25	75	25	75
$R_{a\,c}$ $R_{d\,c}$	1 55	2 48	1 45	1 42	1 65	1 54	2 46	4 85
Field resistance	0 59	0 284	0 503	0 874	0 43	0 425	0 685	0 434
at temperature, degrees centigrade	25	75	25	75	25	75	25	75
Friction and windage, kilowatts	7 0	162 3	20 0	24 2	59 5	60	110	500
Moment of inertia, pound-feet²	115,000		3 879,000		9 540,000		1,767 000	

OPEN-CIRCUIT CHARACTERISTICS

Abscissæ field current	Ordinates, open-circuit terminal volts							
	A	B	C[1]	D	E	F[1]	G	H[1]
50	1,580	760	6,900	5,430	.	6,400	2,550	7,000
75	2,230	1,140	9,660	8,000	.	9,000	3,750	10,400
100	2,675	1,520	11,700	10,180	7,500	10,900	4,930	13,200
125	2,945	1,860	12,920	11,900		12,200	5,950	15,800
150	3,115	2,165	13,770	13,100	11,100	13,170	6,790	18,000
175	3,225	2 440	14,450	14,050		13,930	7,440	19,800
200	3,310	2,670		14,700	13,700	14,520	7,870	21,200
225		2,880		15,100	14,650	15,050	8,150	22,300
250		3 060		15,350	15,460	......	......	23,200
300		3,340		15,500	16,640	......	......	24,400
350					17,300			

[1] Multiply field amperes (abscissæ) by 2

ZERO-POWER-FACTOR CHARACTERISTICS

Alternator	Armature current	Field current when terminal volts are zero	Field current when terminal volts are rated value
A	250	81	193
B	1,500	167	345
C	420	165	415
D	460	120	257
E	518	191	498
F	840	187	554
G	1,490	139	340
H	1,479	290	514

OPEN-CIRCUIT CORE LOSS

Abscissæ core loss, kilowatts	Ordinates open-circuit terminal volts							
	A[1]	B	C[2]	D	E	F	G	H[3]
25	960	1,500	4,500	7,200	6,700	4,500	3,530	8,800
50	1,400	2,140	6,350	9,700	9,950	6,600	4,800	11,400
75	1,740	2,530	7,900	11,100	11,900	8,300	5,600	13,200
100	2,020	2,800	9,200	12,200	13,200	9,550	6,200	14,700
125	2,260	3,000	10,200	13,130	14,130	10,600	6,700	15,800
150	2,460	3,150	11,000	14,000	14,800	11,500	7,050	16,700
175	2,630	......	11,650	14,800	15,350	12,300	7,380	17,300
200	2,780	......	12,200	......	......	13,000	7,650	17,900
225	......	......	12,700	......	.. .	....	.....	18,300

[1] Divide abscissæ (core loss) by 10.
[2] Divide abscissæ (core loss) by 2.
[3] Multiply abscissæ (core loss) by 2.

TYPICAL SATURATION CURVE

Per Cent Normal Field Current	Per Cent Normal Air-gap Flux
39.0	46 8
53.7	63.6
73.2	81.8
100.0	100.0
122.0	111.0
141.5	118.0
171.0	126.6
207.0	134.5
244.0	141.0
275.5	145.5

CHAPTER III

SYNCHRONOUS MOTOR

1. A 1350-hp., 2-phase synchronous motor has 6 slots per pole with 6 series conductors per slot. The pole pitch is 6.25 in., and the coil pitch is 4 slots. The armature core is 12 in. long. The flux density in the air gap is sinusoidally distributed and has a maximum value of 8000 gausses at the center of the field poles. In one of the phases there is a direct current of 350 amp. The other phase is open. What is the tangential force per pole on the armature when the conductors which are carrying the current are directly opposite the field poles?

2. A 1350-hp., 2-phase synchronous motor has 18 slots per pole with 6 series conductors per slot. The pole pitch is 16.25 in., and the coil pitch is 12 slots. The armature core is 14 in. long. The flux density in the air gap is sinusoidally distributed and has a maximum value of 8000 gausses at the center of the field poles. There is a direct current of 350 amp. in each of the phases. What is the tangential force per pole on the armature when the relative position of the field and armature is such that the force is a maximum?

3. A 3-phase, Δ-connected synchronous motor has 12 slots per pole with 8 series conductors per slot. The pole pitch is 7.75 in., and the coil pitch is 10 slots. The armature core is 5 in. long. The flux density in the air gap is sinusoidally distributed and has a maximum value of 7500 gausses at the center of the field poles. There is a direct current of 40 amp. supplied at two of the terminals. What is the tangential force per pole on the armature when the conductors which are carrying the greater current are directly opposite the field poles?

4. A 20,000-kv.-a., 10-pole, Y-connected synchronous condenser has 15 slots per pole with 4 series conductors per slot. The diameter of the armature core at the air gap is 75 in., and its length is 54 in. The coil pitch is 12 slots. The flux density is sinusoidally distributed along the air gap and has a maximum value of 8000 gausses at the center of the field poles. A direct

current of 1500 amp. is supplied at two of the three terminals. The third terminal is free. The rotor is turned into such a position that the torque on it is maximum. What is this maximum torque?

5. A 40,000-kv.-a., 12-pole, Y-connected synchronous condenser has 15 slots per pole with 8 series conductors per slot. The diameter of the armature core at the air gap is 100 in., and its length is 80 in. The coil pitch is 13 slots. Each phase of the armature winding consists of 6 parallel circuits. The flux densit is sinusoidally distributed along the air gap and has a maximum value of 8500 gausses at the center of the field poles. Two of the armature terminals are connected together, and a direct current of 2800 flows through the armature between these terminals and the third terminal. The rotor is turned into such a position that the torque is maximum. What is this maximum torque?

6. A 960-kv.-a., 3-phase, Y-connected synchronous motor has 18 slots per pole with 8 series conductors per slot. The coil pitch is 12 slots, and the pole pitch is 16.25 in. The flux per pole is 8×10^6 maxwells and is sinusoidally distributed along the air gap. This motor is running at synchronous speed and is supplied with single-phase current of 120 amp. at two of its terminals. The third terminal is free. (*a*) When the internal power factor is unity, what is the instantaneous tangential force per pole on the armature (1) at the moment that the current is a maximum, (2) at the moment that the current is one-half of its maximum value? (3) What is the average value of the tangential force per pole? (*b*) When the internal power factor is 0.866, what is the instantaneous tangential force per pole on the armature (1) at the moment that the current is a maximum, (2) at the moment that the current is one-half of its maximum value? (3) What is the average value of the tangential force per pole?

7. A 15 kv.-a., 3-phase, Δ-connected synchronous motor has 12 slots per pole with 8 series conductors per slot. The coil pitch is 10 slots, and the armature core is 5 in. long. The flux density is sinusoidally distributed along the air gap and has a maximum value of 8000 gausses at the center of the field poles. This motor is running at synchronous speed and is supplied with single-phase current of 40 amp. at two of its terminals. The third terminal is free. (*a*) When the internal power factor is

unity, determine the tangential force per pole on the armature at each of four equally spaced time intervals during the half-cycle of current, the first being when the current is zero. What is the average value of the tangential force per pole? (*b*) When the internal power factor is zero, determine the tangential force per pole on the armature at each of four equally spaced time intervals during the half-cycle of current, the first being when the current is zero. What is the average value of the tangential force per pole?

8. A 430 kv-a., 2-phase synchronous motor has 12 slots per pole with 8 series conductors per slot. The coil pitch is 10 slots, and the pole pitch is 13.85 in. The length of the armature core is 11.5 in. The flux density in the air gap is sinusoidally distributed and has an average value of 6200 gausses. This motor is running at synchronous speed and is supplied with balanced 2-phase currents of 100 amp. per phase. (*a*) When the internal power factor is unity, what is the instantaneous tangential force per pole on the armature (1) at the moment that the current is a maximum, (2) at the moment that the current is one-half of its maximum value? (3) What is the average value of the tangential force per pole? (*b*) When the internal power factor is 0.866, what is the instantaneous tangential force per pole on the armature (1) at the moment that the current is a maximum, (2) at the moment that the current is one-half of its maximum value? (3) what is the average value of the tangential force per pole?

9. A 400-hp., 3-phase, Y-connected synchronous motor has 12 slots per pole with 8 series conductors per slot. The coil pitch is 10 slots, and the pole pitch is 14 in. The length of the armature core is 11 in. The flux density in the air gap is sinusoidally distributed and has a maximum value of 7500 gausses at the center of the field poles. (*a*) When this motor receives 100 amp. per terminal at an internal power factor of unity, what is the tangential force per pole acting on the armature? (*b*) When this motor receives 100 amp. per terminal at an internal power factor of 0.8, what is the tangential force per pole acting on the armature?

10. An 80-hp., 3-phase, Y-connected synchronous motor has 18 slots per pole with 30 series conductors per slot. The coil pitch is 11 slots, and the length of the armature core is 5 in. The flux density in the air gap at the center of the poles is 8000 gausses, and an analysis of the distribution shows it to consist of a funda-

mental and a 20 per cent third harmonic in phase with the fundamental. The distribution is symmetrical about the polar axis. The motor is running at synchronous speed. (*a*) If there is a sinusoidal current of 22 amp. at an internal power factor of unity in one phase[1] of this motor, what is the tangential force per pole on the armature at the moment that the current is maximum? What is the average value of this force? (*b*) If this motor is supplied with a single-phase current of 22 amp. at two of its terminals at an internal power factor of unity, what is the tangential force per pole on the armature at the moment that the current is maximum? What is the average value of this force?

11. A 2000-kv.-a., 4-pole synchronous motor has 72 slots with 4 series conductors per slot. The coil pitch is 13 slots. Each phase of the armature winding has 2 parallel paths. The diameter of the armature at the air gap is 32 in., and the length of the core is 37 in. The flux density in the air gap at the center of the pole is 8400 gausses, and an analysis of the distribution shows that it consists of a fundamental and a 20 per cent third harmonic in phase with the fundamental. The distribution is symmetrical about the polar axis. The motor is running at synchronous speed. (*a*) If the coils are connected to form a symmetrical 2-phase armature winding and balanced line currents of 550 amp. are supplied at an internal power factor of unity, what torque is developed at the moment that one of the currents is maximum? What is the maximum value of the instantaneous torque? What is the average value of the torque? (*b*) If the coils are arranged to form a symmetrical 3-phase, Y-connected armature winding and balanced line currents of 550 amp. are supplied at an internal power factor of unity, what torque is developed at the moment that one of the currents is maximum? What is the maximum value of the instantaneous torque? What is the average value of the torque?

12. A single-phase, 6-pole, 60-cycle synchronous motor receives 100 amp. at unity power factor from a 230-volt circuit. The moment of inertia of the rotating part is 6×10^7 g.-cm.^{2} If all losses are neglected, what is the maximum change in speed when the motor is running in synchronism? What is the maximum swing of the rotor in electrical radians from its mean position?

13. A 960-kv.-a., 6-pole, 3-phase, 60-cycle synchronous motor receives 120 amp. at two of its terminals from a 4600-volt circuit.

[1] Between line terminal and neutral.

The third terminal is free. The moment of inertia of the rotor is 2160 lb.-ft.^{2} If all losses are neglected, what is the maximum change in speed when the motor is running in synchronism? What is the maximum swing of the rotor in electrical degrees from its mean position?

14. A 20,000-kv.-a., 10-pole, 3-phase, 60-cycle synchronous condenser receives 1000 amp. at 11,000 volts from a single-phase circuit. One of the armature terminals is free. The moment of inertia of the rotor is 255,000 lb.-ft.^{2} If all losses are neglected, what is the maximum change in the angular velocity when the motor is running in synchronism. What is the maximum swing of the rotor in electrical degrees from its mean position?

15. A 3-phase, 60-cycle, Δ-connected alternating-current generator is rated to deliver 15 kv.-a. at 230 volts. The field structure has 6 poles each of which is wound with 398 turns. The armature core has 4 slots per pole per phase with 8 inductors in series per slot. Each inductor is 5 in. long. The hot resistance of the armature measured between any two terminals is 0.126 ohm. The effective resistance is 1.6 times the ohmic resistance. In calculating the leakage reactance, assume 8 leakage lines per ampere per inch of inductor. The open- and short-circuit characteristics are given by the following data:

Field current	Open circuit	Short circuit
	Terminal potential	Armature current
2.0	104	22
4.0	199	44
5.0	240	55
6.0	275	
7.5	315	

This generator is running as an overexcited synchronous motor and receives 15 kw. at its rated potential and 0.8 power factor. Calculate the field current by (*a*) the general method, (*b*) the synchronous-impedance method, (*c*) the m.m.f. method.

16. A 3-phase, 5000-volt, 25-cycle synchronous motor has a full-load capacity of 1100 hp. The field structure consists of 32 poles each of which is wound with 79.5 turns. The armature core has 192 slots with 14 inductors in series per slot. The

armature winding is Y-connected. The effective resistance of the armature winding is 0.38 ohm per phase. In calculating the leakage reactance, assume 75 leakage lines per ampere per inductor. The open- and short-circuit characteristics are given by the following data:

Field ampere-turns per pole	Open circuit	Short circuit
	Terminal potential	Armature current
4,000	3,200	108
6,000	4,330	162
10,000	5,460	
12,000	5,800	
14,000	6,060	

This motor receives 760 kw. at its rated potential and 0.83 power factor. The excitation is less than normal. Calculate the field current by (*a*) the general method, (*b*) the synchronous-impedance method, (*c*) the m.m.f. method.

17. A 3-phase, 5500-volt, 50-cycle synchronous motor has a full-load capacity of 2000 hp. The field structure has 72 poles each of which is wound with 35 turns. The armature core has 1 slot per pole per phase with 12 inductors per slot. The armature winding is connected in Y. The armature resistance measured between any two terminals is 0.536 ohm, and the ratio of effective to ohmic resistance is 1.35. In calculating the leakage reactance, assume 67 leakage lines per inductor per ampere. The data for the open- and short-circuit characteristics are:

Field current	Open circuit	Short circuit
	Terminal potential	Armature current
150	5,100	300
200	5,900	400
250	6,500	
300	6,800	
350	7,100	

This motor receives 960 kw. at its rated potential and 0.68 power factor. The excitation is greater than normal. Calculate the field current by (*a*) the general method, (*b*) the synchronous-impedance method, (*c*) the m.m.f. method.

18. A 3-phase, 2200-volt, 50-cycle synchronous motor is rated to deliver 1000 hp. when operating at unity power factor. The field structure has 64 poles each of which is wound with 50 turns. The resistance of the field circuit is 0.516 ohm. The armature core has 384 slots with 3 inductors in series per slot. Each inductor is 10 in. long. The hot resistance of the armature measured between terminals is 0.264 ohm. The ratio of effective to ohmic resistance is 1.3. In calculating the leakage reactance, assume 6.5 lines per ampere per inch of inductor. The armature windings are connected in Y. The open- and short-circuit characteristics are given by the following data:

Field current	Open circuit	Short circuit
	Terminal potential	Armature current
40	1450	225
50	1840	280
60	2220	
80	2860	
100	3380	

The rotational losses at normal potential are 17.2 kw. This motor delivers 1000 hp., and the excitation is greater than normal and is adjusted so that the motor is operating from a 2200-volt circuit at a power factor of 0.93. Calculate the potential impressed on the field circuit, using (*a*) the general method, (*b*) the synchronous-impedance method, (*c*) the m.m.f. method.

19. A 2-phase, 10,000-volt synchronous motor is rated to deliver 4500 hp. when operating at unity power factor. The armature has an effective resistance of 0.64 ohm per phase. The open- and short-circuit characteristics are given by the following data:

Field current	Open circuit	Short circuit
	Terminal potential	Armature current
100	7,700	220
200	10,200	430
250	10,900	
300	11,500	
375	12,200	

This motor is delivering 3760 hp. with an efficiency, exclusive of field loss, of 95.6 per cent, and the field current is adjusted so that the motor takes a leading current at 0.91 power factor. Calculate the field current by (*a*) the synchronous-impedance method, (*b*) the m.m.f. method.

20. The full-load capacity of a 3-phase, 13,500-volt synchronous motor is 2200 hp. The armature windings, which are connected in Y, have an effective resistance of 1.52 ohms per phase. The open- and short-circuit characteristics are given by the following data:

Field current	Open circuit	Short circuit
	Terminal potential	Armature current
50	7,500	75
100	10,100	155
150	14,700	227
200	15,800	
250	16,700	

Calculate the field current by the synchronous-impedance method when this motor receives 1640 kv.-a. at 0.75 power factor, with excitation (*a*) greater than normal, (*b*) less than normal.

21. The synchronous motor described in problem 20 receives 1250 kw. at 0.75 power factor. Calculate the field current by the m.m.f. method, with excitation (*a*) greater than normal, (*b*) less than normal.

22. Compute the field current of synchronous motor A, . . D, . . . or H by (*a*) the general method, (*b*) the synchronous-impedance method when the motor receives its rated kilovolt-

amperes at (1) 0.8 power factor lagging, (2) 0.8 power factor leading. Determine the necessary reactance or reaction constants at normal saturation.

23. Determine the per cent values of the following constants at normal saturation of synchronous motor A, . . . D, . . . or H: armature resistance, armature leakage reactance, armature synchronous reactance, armature reaction.

24. A synchronous motor has an armature resistance of 0.75 per cent and a synchronous reactance of 80 per cent. If this motor receives its rated current at rated terminal potential and a power factor of (*a*) 0.80 lagging, (*b*) 0.80 leading, what per cent must its excitation be of its normal value?

25. A synchronous motor has a resistance of 0.72 per cent, a leakage reactance of 11 per cent, and an armature reaction of 65 per cent. Determine the field excitation in per cent of its normal value when this motor receives its rated power at (*a*) 0.80 power factor lagging, (*b*) 0.80 power factor leading. Use the open-circuit characteristic given on page 112.

26. A 5000-kv.-a., 4400-volt, 60-cycle 3-phase, Y-connected synchronous motor has an effective armature resistance of 0.51 ohm per phase, a synchronous reactance of 36 ohms per phase at zero power factor, and a synchronous reactance of 22 ohms per phase at an internal power factor of unity. What must be the excitation of this motor when it receives its rated kilovolt-amperes at rated potential and a power factor of (*a*) 0.75 lagging, (*b*) 0.75 leading?

27. Compute the field current of synchronous motor A, . . . D, . . . or H by the double-reactance method when the motor receives its rated kilovolt-amperes at (*a*) 0.70 power factor lagging, (*b*) 0.70 power factor leading. Assume that the synchronous reactance at an internal power factor of unity is 0.62 of the synchronous reactance at zero power factor.

28. A 3-phase synchronous motor has a resistance per phase of 0.75 per cent, a synchronous reactance per phase of 50 per cent at an internal power factor of unity, and a synchronous reactance per phase of 80 per cent at zero power factor. What must be its excitation when this motor receives its rated kilovolt-amperes at (*a*) 0.70 power factor lagging, (*b*) 0.70 power factor leading?

29. Concerning the alternator described in problem 15, the following additional data are given: The field current is supplied at 110 volts. The friction and windage loss is 310 watts at nor-

mal speed. The core loss is 280, 480, and 610 watts for generated armature potentials of 199, 240, and 275 volts, respectively. What is the efficiency of this generator when it is running as an overexcited synchronous motor and receives 15 kw. at 0.8 power factor? Calculate the field current by (*a*) the general method, (*b*) the synchronous-impedance method, (*c*) the m.m.f. method.

30. Concerning the synchronous motor described in problem 16, the following additional data are given: The resistance of the field circuit is 0.82 ohm. The friction and windage loss at normal speed is 7.6 kw. The core loss due to rotation is 22.3 kw. at 5460 volts and may be assumed to vary as the square of the generated armature potential. What is the efficiency of this motor under the conditions described in problem 16? Calculate the field current by (*a*) the general method, (*b*) the synchronous-impedance method, (*c*) the m.m.f. method.

31. Concerning the synchronous motor described in problem 17, the following additional data are given: The field circuit has a resistance of 0.376 ohm. The friction and windage loss is 8.4 kw. The core loss due to rotation is 20.2 kw. at 5500 volts and may be assumed to vary as the square of the generated armature potential. What is the efficiency of this motor under the conditions described in problem 17? Calculate the field current by (*a*) general method, (*b*) the synchronous-impedance method, (*c*) the m.m.f. method.

32. A 3-phase, 2200-volt synchronous motor is rated to deliver 1000 hp. when operating at unity power factor. The armature windings, which are connected in Y, have an effective resistance of 0.172 ohm per phase. The resistance of the field circuit is 0.576 ohm. The friction, windage, and core losses are 17.2 kw. and may be assumed constant. The open- and short-circuit characteristics are given by the following data:

Field current	Open circuit	Short circuit
	Terminal potential	Armature current
40	1,450	225
50	1,840	280
60	2,220	
80	2,860	
100	3,380	

What is the efficiency of this motor when it delivers 960 hp. and is operating at 0.83 power factor from a 2200-volt circuit if the excitation is (*a*) greater than normal, (*b*) less than normal? Calculate the field current by the synchronous-impedance method.

33. A 2-phase, 2200-volt synchronous motor has a full-load capacity of 5000 hp. when operating at unity power factor. The armature has an effective resistance of 0.0255 ohm per phase. The resistance of the field circuit is 0.37 ohm. The friction and windage loss is 19.0 kw. The core loss due to rotation is 45.2 kw. at 2200 volts and may be assumed constant. The open- and short-circuit characteristics are given by the following data:

Field current	Open circuit	Short circuit
	Terminal potential	Armature current
66 7	680	606
133 0	1,360	1,210
200 0	2,000	
267 0	2,480	
300 0	2,660	

What is the efficiency of this motor when it receives 3200 kw. at 0.80 power factor if the excitation is (*a*) greater than normal, (*b*) less than normal? Calculate the field current by the m.m.f. method.

34. The following test data are given on a 1340-hp., 11,000-volt, 3-phase synchronous motor. The armature effective resistance is 0.94 ohm per phase, and the resistance of the field winding is 3.11 ohms. The armature windings are connected in Y.

Field current	Open-circuit terminal potential	Core loss	Terminal potential for $I_a = 60$, $PF = 0$
20	8,400	11,600	
30	11,000	19,400	
40	12,700	25,600	
50	13,800	......	9,800
60	14,700	......	11,100
70	15,500	......	12,100

The friction and windage loss is 12.1 hp. What are the efficiency and output of this motor when it receives 68 amp. per terminal at 11,550 volts if the excitation is greater than normal and is adjusted so that the power factor is 78.4 per cent?

35. The following test data are given on a 6500-hp., 6600-volt, 3-phase synchronous motor. The effective resistance of the armature winding is 0.081 ohm per phase, and the resistance of the field winding is 0.549 ohm. The armature windings are connected in Y.

Field current	Open-circuit terminal potential	Core loss, kilowatts	Terminal potential I_a = 438, PF = 0
100	4,800	45	1,750
150	6,470	85	4,200
200	7,400	120	5,700
250	7,930	...	6,600
275	8,150	...	6,900

The friction and windage loss is 62.8 hp. What are the efficiency and output of this motor when it receives 450 amp. at unity power factor and its rated potential?

36. The following test data are given on a 1340-hp., 13,800-volt, 3-phase synchronous motor. The armature windings, which are connected in Y, have an effective resistance of 2.18 ohms per phase. The resistance of the field circuit is 0.541 ohm.

Field current	Open-circuit terminal potential	Terminal potential I_a = 42, PF = 0	Core loss, kilowatts
41.2	......	0	....
50	8,800	.....	7.5
80	13,000	......	16.6
110	15,600	10,750	25.4
140	17,250	13,250	33.5
180	18,900	15,600	

The friction and windage loss is 11.2 hp. What is the efficiency of this motor when it delivers 1200 hp. if the excitation is greater than normal and is adjusted so that the motor takes an armature current of 47.6 amp. at a terminal potential of 13,500 volts?

37. Compute the losses and efficiency when synchronous motor A, . . . D, . . . or H receives its rated kilovolt-

amperes at (*a*) unity power factor, (*b*) 0.80 power factor leading, (*c*) 0.80 power factor lagging. In computing the losses, determine the field current by (1) the general method, (2) the m.m.f. method, (3) the synchronous-impedance method, (4) the double-reactance method, assuming that the ratio of the two reactances is 0.6.

38. A 3-phase, 60-cycle, Y-connected synchronous motor is rated to receive 1000 kv.-a. at 13,800 volts. The armature has an effective resistance of 2.18 ohms per phase. The data for the open-circuit characteristic and the full-load current saturation curve at zero power factor are:

Field current	Open-circuit terminal volts	Saturation curve, 42 amperes at zero power factor	Core loss, kilowatts
41.2	......	0	....
50	8,800	......	7.5
110	15,600	10,750	25.4
140	17,250	13,250	33.5
180	18,900	15,600	

The friction and windage loss is 11.2 hp. The field resistance is 0.54 ohm. This synchronous motor is run at no load from a 13,800-volt line with its excitation adjusted so that it takes a leading current of 50 amp. What is the necessary field current? If the efficiency of the exciter which is on the motor shaft is 0.90, what power does the motor take?

39. A 1000-kv.-a., 3-phase, 6600-volt synchronous condenser is taking full-load kilovolt-amperes at essentially zero power factor (leading). Calculate the power that the condenser takes from the 3-phase line.

Field current	Terminal potential zero power factor, $I_a = 123$	Open circuit, volts	Core loss, kilowatts
30	.....	5,300	10.5
35	.....	6,000	14.0
40	.....	6,650	18.5
46.3	0	7,330	24.3
55	1,580	8,000	31.0
65	3,400	8,630	38.3
94	6,600		

The friction and windage loss is 30 hp. The resistance between terminals is 0.512. The ratio of $R_{ac}:R_{dc}$ is equal to 2.25. The field resistance is 0.978. The self-driven exciter has an efficiency of 0.90.

40. Compute the losses when the synchronous condenser E, F, G, or H receives its rated kilovolt-amperes and is (*a*) overexcited, (*b*) underexcited. Compute the field current by (1) the general method, (2) the m.m.f. method, (3) the synchronous-impedance method, (4) the double-reactance method, assuming that the ratio of the two reactances is 0 60.

41. A single-phase, 6-pole, 60-cycle synchronous motor receives 100 amp. at unity power factor from a 230-volt circuit. The moment of inertia of the rotating part is 6×10^7 g. - cm.^{2}, *i.e.*, 6×10^7 c.g.s. units. What is the time in seconds between the maximum and minimum speeds? What is the maximum change in the kinetic energy of the rotor?

42. The synchronous motor A or C or the synchronous condenser E or G, while running with no connected shaft load, is receiving its rated line current, at two of its three terminals, at its rated line potential. Neglecting all of the losses, what is the maximum change in speed during a revolution? What is the maximum electrical angular displacement of the rotor from its mean position?

43. A synchronous motor, whose armature windings are connected in Y, has an effective resistance of 0.94 ohm and a synchronous reactance of 36 ohms per phase. This motor receives a line current of 60 amp. at a terminal potential of 11,000 volts, and the excitation is adjusted so that the power factor is 0 85. What power does the motor receive? What is the excitation e.m.f. if the excitation is (*a*) greater than normal, (*b*) less than normal?

44. A 2-phase synchronous motor has an effective armature resistance of 0.64 ohm and a synchronous reactance of 13 7 ohms per phase. The motor receives 3000 kw. at a line potential of 10,000 volts, and the excitation is adjusted so that the line current is 200 amp.

At what power factor is this motor operating? What is the excitation e.m.f. if the excitation is (*a*) greater than normal, (*b*) less than normal?

45. A 5000-hp. synchronous motor is operated from a 2200-volt, 2-phase circuit. The effective resistance of the armature is

0.0254 ohm per phase. The field winding has 60 turns per pole and a total resistance of 0.37 ohm.

Ampere-turns per pole	Open-circuit terminal potential	Short-circuit armature current
4,000	680	606
8,000	1,360	1,210
12 000	2,000	
16,000	2,480	
18,000	2,660	

At no load, this motor takes 67.5 kw. at 2200 volts when the excitation is adjusted so that it operates at 0.86 power factor. How much must the excitation be increased in order that the motor will deliver its rated load and operate at this same power factor? Use the m.m.f. method for calculating the field current.

46. A 3-phase synchronous motor, whose armature windings are connected in Δ, has an effective resistance of 0.302 ohm and a synchronous reactance of 4.36 ohms per phase. This motor receives a line current of 40 amp. at 230 volts, and the field current is adjusted so that the excitation e.m.f. is 310 volts. What power does the motor receive? At what power factor is it operating?

47. A 2400-volt, 3-phase, synchronous motor has a full-load capacity of 1340 hp. The effective resistance of the armature is 0.067 ohm per phase, and the synchronous reactance is 2.64 ohms per phase. The armature windings are connected in Y. The resistance of the field circuit is 0.427 ohm. The rotational losses at normal potential are 26.6. kw.

This motor is operated from a 2400-volt circuit at 0.82 power factor and is delivering 1220 hp. What is the line current, and what is the necessary excitation e.m.f.? Calculate the excitation e.m.f. for both under- and overexcitation.

48. A 135-hp. synchronous motor is operated from a 480-volt, 2-phase circuit. The effective resistance of the armature is 0.135 ohm per phase at normal running temperature. The rotational losses at normal potential are 5.7 kw.

Field current	Terminal potential on open circuit	Armature current on short circuit
10	397	158
17	527	
25	600	
35	655	

With the greatest allowable excitation, the motor takes a current of 135 amp. when delivering its rated load. At what power factor does it then operate? What is the field current? Use what you consider the best method for calculating the field current.

49. A 3-phase synchronous motor, whose armature windings are connected in Y, has an effective resistance of 0.172 ohm and a synchronous reactance of 2.12 ohms per phase. This motor receives 750 kw. at a line potential of 2200 volts, and the field current is adjusted so that the excitation e.m.f. is 2800 volts. What is the line current? At what power factor is the motor operating?

50. A 2200-volt, 2-phase synchronous motor has a full-load capacity of 5000 hp. The full-load efficiency of the armature, with the field current adjusted for unity power factor, is 96.1 per cent. The armature winding has an effective resistance of 0.025 ohm and a synchronous reactance of 0.72 ohm per phase. The motor receives a constant power of 3000 kw. at 2200 volts. If the current is limited to 130 per cent of its full-load value, what is the greatest allowable excitation e.m.f.? At what power factor would the motor be operating?

51. A 3-phase, 13,500-volt synchronous motor is rated to deliver 2200 hp. when operating at unity power factor. The armature has an effective resistance of 1.52 ohms per phase. The armature windings are connected in Y.

Field current	Open circuit terminal potential	Short circuit armature current
50	7,500	75
100	10,100	155
150	14,700	227

The rotational losses at normal potential are 68 hp. If the maximum allowable current is 125 per cent of the full load current, over what range should it be possible to vary the field current when the motor is delivering a constant load of 2000 hp.? Use the m.m.f. method for calculating the field current.

52. A 1340-hp., 3-phase synchronous motor receives a constant power of 860 kw. from an 11,000-volt circuit. The armature windings, which are connected in Y, have an effective resistance of 0.94 ohm and a synchronous reactance of 56 ohms per phase. Over what range can the excitation e.m.f. be varied so that the current will not exceed 135 per cent of its full-load value, which is 62.5 amp.?

53. A 3-phase, 5000-volt synchronous motor, whose armature windings are connected in Y, has an effective resistance of 0.40 ohm and a synchronous reactance of 15.4 ohms per phase. The rotational losses are 30 kw. and may be assumed constant. The greatest excitation e.m.f. that can be obtained is 3520 volts per phase. When the motor is delivering its full load of 1100 hp., over what range can the power factor be varied? What is the armature current at each of the limiting conditions? Compare these with the full-load armature current.

54. Neglecting the field copper loss, the efficiency of a 2200-hp. 3-phase synchronous motor is 96.0 per cent at full load when the motor is operating at unity power factor. Assume that the rotational losses are constant. The armature windings, which are connected in Y, have an effective resistance of 1.52 ohms and a synchronous reactance of 37.4 ohms per phase. With the motor delivering 2000 hp., the field current is adjusted so that the motor takes a leading current of 85 amp. from a 13,500-volt constant potential circuit. (*a*) At what power factor is the motor operating? What is the excitation e.m.f.? (*b*) If this load is thrown off, what current will the motor take, and at what power factor will it be operating? The excitation is unchanged.

55. The rotational losses of a 1340-hp., 2400-volt, 3-phase synchronous motor are 43 hp. and may be assumed constant. The armature windings, which are connected in Y, have an effective resistance of 0.067 ohm and a synchronous reactance of 1.64 ohms per phase. (*a*) What is the least power factor at which the motor can be operated at no load so that the current will not exceed 135 per cent of its full-load value? If the motor is over-excited, what is the excitation e.m.f.?

56. When operating at unity power factor, the full-load losses of an 1100-hp., 5000-volt, 3-phase synchronous motor are armature copper loss, 13.9 kw.; field copper loss, 18.6 kw.; rotational losses, 27.8 kw. Assume that the rotational losses are constant. The armature windings, which are connected in Y, have a synchronous impedance of 12.4 ohms per phase. If the current is limited to 130 per cent of its full-load value, what is the least power factor at which this motor can be operated when it is delivering full load? What is the necessary excitation e.m.f. if the motor is overexcited?

57. The synchronous motor described in problem 35 is rated to deliver 6500 hp. when operating at unity power factor. If the maximum allowable current is 130 per cent of its full-load value, what is the least power factor at which it can operate when delivering its rated load? What is the greatest allowable value of the field current at full load under this condition?

58. A 3-phase synchronous motor receives line currents of 226 amp. at a terminal potential of 2180 volts and delivers 812 hp. The no-load rotational losses are 23 hp. and may be assumed constant. The armature windings, which are Y-connected, have an effective resistance of 0.172 ohm and a synchronous reactance of 2.12 ohms per phase. At what power factor is the motor operating? Neglecting the field copper losses, what is the efficiency?

59. At no load, a 3-phase synchronous motor takes line currents of 1.52 amp. at 11,000 volts if the field current is adjusted for a minimum armature current. The armature windings, which are connected in Y, have an effective resistance of 0.94 ohm and a synchronous reactance of 56 ohms. When the motor receives 960 kw. at 11,000 volts and the excitation is adjusted so that the line current is 72 amp., what is the output? If the excitation is greater than normal, what is the excitation e.m f.?

60. The no-load rotational losses of a 1340-hp., 3-phase synchronous motor are 34.6 kw. The armature windings are connected in Y and have an effective resistance of 0.067 ohm and a synchronous reactance of 2.64 ohms per phase. This motor is operated from a 2400-volt circuit, and when delivering its rated output the excitation is adjusted so that the motor takes a leading current at 0.83 power factor. What is the power input? What is the excitation e.m.f.?

61. At no load, a 150-hp., 2-phase synchronous motor takes 7.6 kw. at 480 volts when the excitation is adjusted for a minimum armature current. Under load, this motor takes 108 amp. at 485 volts when the excitation is adjusted so that the power factor is 0.78. The effective resistance of the armature is 0.118 ohm, and the synchronous reactance is 2.13 ohms. What is the output? What is the excitation e.m.f. if the field current is (*a*) greater than normal, (*b*) less than normal?

62. A 3-phase, 6600-volt synchronous motor is operated at its rated potential and delivers its rated output of 6500 hp. In order that the motor shall take a large leading current, the field current is adjusted for an excitation e.m.f. of 8100 volts. The no-load rotational losses are 138 kw. and may be assumed constant. The armature windings are connected in Y and have an effective resistance of 0.081 ohm and a synchronous reactance of 2.8 ohms. What is the power factor? What current does the motor take?

63. A 2-phase, 10,000-volt synchronous motor has a rated capacity of 4500 hp. The armature has an effective resistance of 0.64 ohm and a synchronous reactance of 23.7 ohms per phase. At no load, with an excitation greater than normal, the motor takes 74 kw. at 10,000 volts, and the line current is 41 amp. With the field excitation unchanged, what current will the motor take when it is delivering its rated output? At what power factor will the motor be operating?

64. The excitation of synchronous motor A, . . . D, . . . or H is adjusted so that it operates at unity power factor when it receives 50 per cent of its rated kilovolt-amperes. With the excitation unchanged, at what power factor will it operate when it receives its rated kilovolt-amperes? With the same excitation, what current will it take at no load? What are the losses in each of these two cases. Use (*a*) the synchronous-impedance method, (*b*) the m.m f. method, (*c*) the double-reactance method, assuming that the ratio of the two reactances is 0.60.

65. Synchronous motor A, . . . D, . . . or H receives power in kilowatts equal to 75 per cent of its rated kilovolt-amperes at its rated potential. If the current is limited to 125 per cent of its rated value, what is the greatest allowable excitation e.m.f.? At what power factor will the motor operate? Use (*a*) the general method, (*b*) the m.m.f. method, (*c*) the synchro-

nous-impedance method, (*d*) the double-reactance method, assuming that the ratio of the two reactances is 0.60.

66. Synchronous motor A, . . . D, . . . or H receives power equal to 70 per cent of its rated kilovolt-amperes at its rated potential. If the current is limited to 130 per cent of its rated value, over what range is it possible to vary the power factor? What is the field current at the two extreme values of power factor? Use (*a*) the general method, (*b*) the m.m.f. method, (*c*) the synchronous-impedance method, (*d*) the double-reactance method, assuming that the ratio of the two reactances is 0.60.

67. Synchronous motor A, . . . D, . . . or H receives power equal to 75 per cent of its rated kilovolt-amperes at (*a*) unity power factor, (*b*) 0.75 power factor lagging, (*c*) 0.75 power factor leading. With the excitation unchanged, what power and current will this motor take when it delivers no shaft load? Use (1) the general method, (2) the m.m.f. method, (3) the synchronous-impedance method, (4) the double-reactance method, assuming that the ratio of the two reactances is 0.60.

68. A 3-phase, 230-volt synchronous motor, whose armature windings are connected in Δ, has an effective resistance of 0.302 ohm and a synchronous reactance of 4.36 ohms per phase. The rotational losses are 750 watts and may be assumed constant. The motor delivers a constant load of 20 hp. What is the least excitation e.m.f. with which the motor will run? What is the armature current at the instant of breakdown?

69. A 20-hp., 230-volt, 3-phase synchronous motor has an effective resistance of 0.302 ohm and a synchronous reactance of 4.36 ohms per phase. The armature windings are connected in Δ. The rotational losses are 750 watts and may be assumed constant. With the maximum excitation e.m.f. of 315 volts, at what load will this motor break down? Compare the current at breakdown with the full-load current for normal excitation.

70. If the ratio of resistance to synchronous reactance is increased to 0.30 by inserting equal resistances in series with each phase of the synchronous motor, what will be the results called for in (*a*) problem 68, (*b*) problem 52, (*c*) problem 53, (*d*) problem 55, (*e*) problem 56, (*f*) problem 69?

71. Synchronous motor A, . . . D, . . . or H is receiving its rated kilovolt-amperes at (*a*) unity power factor, (*b*) 0.80 power factor lagging, (*c*) 0.80 power factor leading. With the

field excitation unchanged, what shaft load can be gradually added before the motor will fall out of step? Use (1) the general method, (2) the m.m.f. method, (3) the synchronous-impedance method, (4) the double-reactance method, assuming that the ratio of the two reactances is 0.6. The armature resistance may be assumed to be negligibly small.

72. Synchronous motor A, . . . D, . . . or H is receiving its rated kilovolt-amperes at (*a*) unity power factor, (*b*) 0.80 power factor lagging, (*c*) 0.80 power factor leading. With the field excitation unchanged, what shaft load gradually added will cause the rotor to shift its relative position 30 electrical deg.? Use (1) the general method, (2) the m.m.f. method, (3) the synchronous-impedance method, (4) the double-reactance method, assuming that the ratio of the two reactances is 0.60. The armature resistance may be assumed to be negligibly small.

73. Synchronous motor A, . D, . . . or H is receiving its rated kilovolt-amperes at (*a*) unity power factor, (*b*) 0.80 power factor lagging, (*c*) 0.80 power factor leading. With the field excitation unchanged, the shaft load is reduced 50 per cent. By what electrical angle does the rotor shift its relative position? Use (1) the general method, (2) the m.m.f., (3) the synchronous-impedance method, (4) the double-reactance method, assuming that the ratio of the two reactances is 0.60. The armature resistance may be assumed to be negligibly small.

74. Synchronous motor A, . . . D, . . . or H is receiving its rated kilovolt-amperes at (*a*) unity power factor, (*b*) 0.80 power factor lagging, (*c*) 0.80 power factor leading. If the field current is reduced 25 per cent, through what relative electrical angle will the rotor swing? The terminal potential and the shaft load are constant. Use (1) the general method, (2) the m.m.f. method, (*c*) the synchronous-impedance method, (*d*) the double-reactance method, assuming that the ratio of the two reactances is 0.60. The armature resistance may be assumed to be negligibly small.

75. What is the pull-out torque of synchronous motor A, . . . D, . . . or H when it is operating at its rated terminal potential and the field current is (*a*) normal, (*b*) 25 per cent greater than normal, (*c*) 25 per cent less than normal? Use (1) the general method, (2) the m.m.f. method, (3) the synchronous-impedance method, (4) the double-reactance method, assuming that the

ratio of the two reactances is 0.60. The armature resistance may be assumed to be negligibly small.

76. What is the maximum shaft load that synchronous motor A, . . . D, . . . or H will deliver when the terminal potential has its rated value and there is no field excitation? Assume that the ratio of the synchronous reactance at internal unity power factor to that at zero power factor is 0.60 and that the resistance is negligibly small.

77. What per cent of its rated output will a synchronous motor deliver when the applied potential is normal and there is no field excitation, if the synchronous reactance at internal unity power factor is 50 per cent and the synchronous reactance at zero power factor is 80 per cent?

78. The following data are given on a 3-phase, Y-connected synchronous motor: 1000 kv.-a; 60 cycles; 6 poles; effective armature resistance, 2.18 ohms per phase; field resistance, 0.611 ohm; field excitation from 110-volt circuit through a regulating rheostat.

Field current	Terminal volts, open circuit	Terminal volts, zero power factor, $I_a = 42$	Rotation losses, open circuit, kilowatts
41 2		0	. . . .
50	8,800		16 7
110	15,600	10,750	34 2
140	17,250	13,250	42 7
180	18,900	15,600	

This motor is operating from a balanced 3-phase, 13,200-volt, 60-cycle system and is receiving 1000 kw. at (*a*) unity power factor, (*b*) 0.80 power factor lagging, (*c*) 0.80 power factor leading. The field rheostat becomes short circuited. If it is assumed that the field current rises abruptly to its steady direct-current value before the speed of the motor is altered in the least degree, what current will the motor take and what torque will it develop at the shaft?

79. When synchronous motor A, . . . D, . . . or H is receiving its rated kilovolt-amperes at (*a*) unity power factor, (*b*) 0.80 power factor lagging, (*c*) 0.80 power factor leading, the field excitation is suddenly increased 25 per cent. If it be

assumed that the field current rises abruptly to this steady value before the speed of the motor is altered in the least degree, what current will the motor take and what torque will it develop at the shaft? Use (1) the general method, (2) the m.m.f. method, (3) the synchronous-impedance method, (4) the double-reactance method, assuming that the ratio of the two reactances is 0.60. The armature resistance may be assumed to be negligibly small.

80. A 1000-hp. synchronous motor is operating at the end of a 3-phase transmission line which has a resistance of 0.58 ohm and a reactance of 0.64 ohm per conductor. The motor is overexcited so that it takes a line current of 216 amp. at a power factor of 0.82 and with a line potential of 2210 volts. What is the line potential at the generating station? What is the efficiency of transmission?

81. A synchronous motor operating at the end of a 3-phase transmission line takes a constant power of 1500 kw. The resistance and reactance of the line are, respectively, 2.2 and 2.6 ohms per conductor. The line potential at the generating station is maintained at 5740 volts. The excitation of the motor is adjusted so that the line loss has its least possible value. What is the terminal potential at the motor? What is the efficiency of transmission?

82. A synchronous motor operating at the end of a 3-phase transmission line which has a resistance of 3.6 ohms and a reactance of 4.1 ohms per conductor takes a constant power of 720 kw. from the line, and the excitation is adjusted so that the line potential is 5000 volts. The line potential at the generating station is also maintained at 5000 volts. (*a*) What current does the motor take? At what power factor is it operating? (*b*) If the motor is Y-connected and has an effective resistance of 0.40 ohm and a synchronous reactance of 15.4 ohms per phase, what is the necessary excitation e.m.f.?

83. Synchronous motor A, . . . D, . . . or H is operating at the end of a feeder which, when the motor takes its rated current, gives resistance and reactance drops per conductor of 10 and 12 per cent of the rated potential of the motor. The field excitation is so adjusted that the potentials at both ends of the feeder are equal to the rated potential of the motor. What is the greatest load that the motor can deliver without taking more than its rated current? Using (*a*) the general

method, (*b*) the m.m.f. method, (*c*) the synchronous-impedance methods (*d*) the double-reactance method, assuming that the ratio of the two reactances is 0.60, what is the field current?

84. At the end of a 3-phase transmission line which has a resistance of 0.62 ohm and a reactance of 0.64 ohm per conductor, there is a synchronous motor whose armature windings are connected in Y and have an effective resistance of 0.172 ohm and a synchronous reactance of 2.12 ohms per phase. The rotational losses of the motor are 17.2 kw. and may be assumed constant. When instruments in the generating station indicate that the transmission line is receiving 780 kw. at 2250 volts and a power factor of 0.88 (leading), what is the output of the motor? What is the line potential at the motor?

85. A 1200-hp. synchronous motor is operated at the end of a 3-phase transmission line which has a resistance of 3.3 ohms and a reactance of 3.7 ohms per conductor. The line potential at the generating station is 5000 volts, and the motor delivers energy to a constant load of 1000 hp. The rotational losses of the motor are 29.8 kw. and may be assumed constant. The armature windings are connected in Y and have a resistance of 0.40 ohm and a synchronous reactance of 10.4 ohms per phase. If the maximum allowable line current is 135 amp., what is the greatest possible terminal potential at the motor? What is the necessary excitation e.m.f. of the motor?

86. At the end of a transmission line which has a resistance of 12.2 ohms and a reactance of 17.4 ohms per conductor, there is a synchronous motor which delivers a constant load of 1300 hp. The armature windings of the motor, which are connected in Y, have an effective resistance of 0.94 ohm and a synchronous reactance of 36 ohms per phase. At no load, with an impressed potential of 11,000 volts, the motor takes a current of 1.52 amp. when the field current is adjusted for unity power factor. The line potential at the generating station is maintained constant at 11,500 volts.

If the line current is limited to 120 per cent of its full-load value, which is 62.5 amp., what is the least additional reactance that should be inserted in each line so that a terminal potential of 12,000 volts may be obtained at the motor? What is the necessary excitation e.m.f. of the motor in this case?

87. The following data are given concerning a 1000 kv.-a., 6600-volt, 3-phase synchronous motor:

Field current	Open-circuit terminal volts	Zero power factor $I = 95$, full-load current	Core loss, kilowatts
42	3,050	0	...
100	6,500	4,200	22
165	7,400	5,700	30
183	8,150	6,900	

The armature resistance is 0.95 ohm between terminals, and the friction and windage loss is 9 kw. This motor is operated at the end of a short transmission line from a 6600-volt generating station. For full-load motor current, the resistance and reactance drops in this line are each 8 per cent. How much additional reactance must be inserted in series with each line conductor in order that the potential at the motor may be maintained at its rated value when the motor delivers 1200 hp. and operates at 0.8 power factor. What is the necessary field excitation of the motor, and what is its efficiency for this load?

88. A 13,800-volt, 3-phase synchronous motor has a full-load capacity of 1350 hp. The armature windings are connected in Y and have an effective resistance of 2.18 ohms and a synchronous reactance of 62 ohms per phase. At no load, with an impressed potential of 13,800 volts, the motor takes 28.2 kw. when the excitation is adjusted for unity power factor. This motor is operated at the end of a transmission line which has a resistance of 22 ohms and a reactance of 28 ohms per conductor. The line potential at the generating station is maintained constant at 14,000 volts. When the motor is delivering 1200 hp., what is the greatest potential at the motor if the armature current is limited to 125 per cent of its full-load value? What is the necessary excitation e.m.f. of the motor?

89. At the end of a 3-phase transmission line which has a resistance of 0.62 ohm and a reactance of 0.64 ohm per conductor, there is a synchronous motor whose armature windings are connected in Y and have an effective resistance of 0.172 ohm and a synchronous reactance of 2.12 ohms per phase. The rotational losses of the motor are 17.2 kw. and may be assumed constant.

When instruments in the generating station indicate that the transmission line is receiving 780 kw. at 2250 volts and a power

factor of 0.88 (leading), what is the output of the motor? What is the line potential at the motor?

90. A 3-phase transmission line has a resistance of 12.6 ohms and a reactance of 16.4 ohms per conductor. The generating station which delivers energy to this line maintains a constant line potential of 14,000 volts. At the end of the line there is a synchronous motor whose armature windings are connected in Y and have an effective resistance of 1.52 ohms and a synchronous reactance of 37.4 ohms per phase. The rotational losses of this motor are 36.8 kw. and may be assumed constant. When the motor is delivering 2000 hp. and the excitation e.m.f. is adjusted to its greatest value of 16,700 volts, what is the terminal potential of the motor? At what power factor is the motor operating?

91. A 1000-kw., 13,800-volt, 3-phase alternating-current generator delivers power over a transmission line which has a resistance of 16.4 ohms and a reactance of 17.2 ohms per conductor to a 1340-hp. synchronous motor. Both generator and motor have their armatures connected in Y. This motor is rated for 11,000 volts and has an effective armature resistance of 0.94 ohms and a synchronous reactance of 46 ohms per phase. The effective resistance and synchronous reactance of the generator are, respectively, 2.18 and 82 ohms per phase. The rotation losses of the motor are 22 kw. and may be assumed constant. For certain excitations of generator and motor, the line current and power factor at the motor are, respectively, 48 amp. and 0.92 (lagging) when the motor delivers 1140 hp. If the excitations are unchanged, what will be the line current and the terminal potentials of the generator and motor if the load on the motor is thrown off?

92. At the end of a 3-phase transmission line are induction motors which take a total load of 1200 kw. at 0.80 power factor. An additional load of 600 hp. should be provided for. Find the kilovolt-ampere capacity of a synchronous motor that will supply this load and will at the same time make it possible to adjust the power factor of the entire load to (*a*) unity, (*b*) 0.95 lagging, (*c*) 0.90 lagging. Assume that the efficiency of the synchronous motor is 92 per cent.

93. An induction motor load at the end of a 3-phase transmission line takes 6000 kw. at 0.60 power factor. A synchronous motor is operating in parallel with the induction motors in order to improve the power factor. The motor has a full-load

capacity of 6500 hp. when operating at unity power factor from a 6600-volt circuit. The armature windings, which are connected in Y, have an effective resistance of 0.081 ohm per phase. The synchronous impedance is 2.57 ohms per phase. The friction and windage losses are 62.8 hp., and the core losses at normal potential are 86 kw. The latter may be assumed to be constant. The synchronous motor is operated so that the resultant power factor of the load is (*a*) 0.90, (*b*) 0.95, and the line potential is 6600 volts. If the current is limited to 125 per cent of its full-load value, what is the greatest power that the synchronous motor can supply? What is the necessary excitation e.m.f. of the synchronous motor at this time?

94. Induction motors at the end of a 3-phase transmission line deliver a total power of 3500 hp. and operate at a resultant efficiency and power factor of 88.0 per cent and 0.65, respectively. The line potential is 13,200 volts. A 1640-kv.-a. synchronous motor is operated in parallel with these motors to improve the power factor of the load and to supply an additional load of 1000 hp. The armature windings of this synchronous motor are connected in Y and have an effective resistance of 1.52 ohms per phase. The rotational losses at normal potential are 57 hp. and may be assumed to be constant.

Field current	Open-circuit terminal potential	Short-circuit armature current
50	7,530	75
100	10,100	155
150	14,700	227
200	15,800	
250	16,700	

At what per cent of its rated capacity must the synchronous motor be operated so that the power factor of the entire load shall be (*a*) unity, (*b*) 0.95? Calculate the necessary field current of the motor for this condition by the m.m.f. method.

95. A 1340-hp., 11,000-volt, 3-phase synchronous motor is operated in parallel with an induction motor load which is taking 960 kw. at 0.80 power factor from an 11,000-volt circuit. The armature effective resistance is 0.94 ohm. The armature windings are Y-connected.

Field current	Open-circuit terminal potential	Core loss	Zero power factor saturation curve, $I_a = 60$
20	8,400	11,600	
30	11,000	19,400	
40	12,700	25,600	
50	13,800	......	9,800
60	14,600	....	11,000
70	15,500	......	12,100

The friction and windage loss is 12.1 hp. If the armature current of this motor is limited to 60 amp., what is the greatest power the motor can deliver if the excitation is adjusted so that the combined power factor of the induction and synchronous motors is (*a*) unity, (*b*) 0.95, (*c*) 0.90? What would be the necessary excitation e.m.f. of the motor?

96. An induction motor load taking 200 kw. is operating at a power factor of 65 per cent. An additional load of 75 kw. must be provided for, either by adding an induction motor which will operate at 0.85 per cent power factor or by adding a synchronous motor (taking a leading current) which is to be of such kilovolt-ampere capacity as will permit the resulting power factor being raised to 95 per cent. (*a*) What is the necessary kilovolt-ampere capacity of the synchronous motor? (*b*) What would be the ratio of the line copper losses under these two conditions? (*c*) Neglecting all losses, what would be the relative kilovolt-ampere capacity of generating apparatus in the power station under these two conditions?

97. In a factory, there is, at present, an induction motor load taking 1000 kw. at 0.71 power factor. It is desired to add other motors, operating at the same power factor, and at the same time a synchronous condenser so adjusted that the new kilovolt-ampere load will just equal the original kilovolt-ampere load and the resulting power factor will be 0.90. Assume that the full-load losses of the synchronous condenser are 6 per cent of its rated capacity. Also, assume that the full-load synchronous-impedance drop is 60 per cent of the rated potential. (*a*) What is the added induction motor load in kilowatts? (*b*) What is the kilovolt-ampere capacity of the smallest synchronous condenser that will accomplish this? (*c*) To what per cent of its rated

potential should it be possible to increase the excitation e.m.f. of the synchronous condenser?

98. A 6600-volt constant-potential generating station supplies power over a transmission line, having an equivalent resistance of 0.65 ohm and an equivalent reactance of 1.25 ohms per conductor, to a load which varies from zero to a current of 400 amp. per terminal at 0.8 power factor lagging. A synchronous condenser is added at the load in order that the line potential there may be maintained constant at 6600 volts under all conditions. (*a*) How must the synchronous condenser be controlled to accomplish this? (*b*) How is it operating at the zero load current and at the 400-amp. load current? (*c*) What is the kilovolt-ampere capacity of the smallest synchronous condenser that will accomplish this purpose? (*d*) Over what range must it be possible to vary its excitation e.m.f. if its full-load synchronous-reactance drop is 75 per cent of the rated potential?

99. A 3-phase transmission line is supplied with power at a constant potential of 6600 volts. The line has a resistance and reactance of 0.6 and 0.4 ohm, respectively, per conductor. At the end of this line is connected a 3-phase synchronous motor, data concerning which are given below.

Field current	Open-circuit terminal potential	Terminal potential $I_a = 438$, $PF = 0$
100	4,800	1,750
150	6,470	4,200
200	7,400	5,700
250	7,930	6,600
275	8,150	6,900

At the end of this line, there is also a constant load taking 300 amp. per terminal at unity power factor in addition to the synchronous motor. The motor is running idle, and its armature current is limited to 438 amp. In your calculations, neglect the losses in the motor. How could the potential at the load be varied? What are the greatest and least values of the line potential at the load? What is the field current of the motor in each case?

100. A constant induction-motor load taking 2500 kw. at 0.85 power factor and with a line potential of 13,200 volts is at the end

of a short transmission line. For this load, the efficiency of transmission is 91.3 per cent, and the potential regulation of the line is 11.2 per cent. A synchronous motor of suitable capacity is added at the load so that when running light with full-load current the resultant power factor at the load is increased to (*a*) unity, (*b*) 0.95. Assume that the efficiency of this synchronous motor at full load and unity power factor is 0.93. The potential at the load is maintained constant. What is the necessary capacity of the synchronous motor? What are the efficiency of transmission and the potential regulation of the line after the synchronous motor is added?

101. A constant-potential 6600-volt generating station supplies power over a 66,000-volt transmission line to a synchronous motor running idle and to a variable load taking a current which does not exceed 400 amp. per terminal at 0.9 power factor. At the generating and receiving ends of this line are transformers connected in Δ-Y and Y-Δ, respectively. At no load, the line potential at the receiving end is 6600 volts. With the secondaries of the transformers at the receiving end short circuited, instruments at the generating station indicate $V_{\text{line}} = 1350$, $I_{\text{line}} = 600$, $P_{\text{total}} =$ 680 kw.

DATA CONCERNING SYNCHRONOUS MOTOR

Field current	Open-circuit terminal potential	Terminal potential $I = 438$ $PF = 0$
100	4,800	1,750
150	6,470	4,200
200	7,400	5,700
250	7,930	6,600
275	8,150	6,900

The synchronous motor is Y-connected and the current per terminal is limited to 438 amp. Neglect all losses in motor.

Describe exactly, but briefly, what would be done to maintain the potential at the load at 6600 volts. Make the necessary calculations for the conditions when the variable load is (*a*) zero, (*b*) greatest, *i.e.*, 400 amp. per terminal at 0.90 power factor.

102. An induction-motor load at the end of a 3-phase, 25-cycle transmission line takes 7600 kw. at 0.75 power factor and with a line potential of 11,000 volts. The resistance and inductance of

the line are, respectively, 1.4 ohms and 6.5 mil-henrys per conductor. A synchronous motor, running light and taking full-load current, is added at the load to improve the power factor and thus increase the capacity of the line. Assume that the full-load efficiency of this motor is 94 per cent when operating at unity power factor. The potential at the load is maintained constant. Induction motors, operating at the same power factor as do the others, are also added at the load, and the synchronous motor is adjusted so that the generating station operates at (*a*) unity power factor, (*b*) 0.95, (*c*) 0.90 power factor. For the same line current in the station as was required before the addition of the synchronous motor, calculate the permissible increase in the induction-motor load. What is the kilovolt-ampere capacity of the necessary synchronous motor? What is the necessary line potential at the generating station before and after the synchronous motor and additional induction motors are connected to the circuit.

103. An induction-motor load taking 5400 kw. at 0.80 power factor and with a line potential of 13,200 volts is at the end of a 3-phase transmission line which has a resistance of 2.38 ohms and an inductance of 7.6 mil-henrys per conductor. The full-load capacity of the generating station is 320 amp. per line. A synchronous motor is to be added at the load both to improve the power factor and to supply additional power. Assume that the efficiency of this synchronous motor and its exciter is 92 per cent at full load when operating at unity power factor. The potential at the load is maintained constant. The frequency is 60 cycles. Calculate the kilovolt-ampere capacity of the synchronous motor so that the generating station can deliver its full-load current at (*a*) unity power factor, (*b*) 0.9 power factor. What additional power can the synchronous motor supply? At what power factor does the synchronous motor operate? What is the necessary line potential at the generating station before and after the synchronous motor is added?

104. An induction-motor load taking 26,000 kw. at 0.80 power factor and with a line potential of 6600 volts is operated at the end of a high-tension transmission line. At the ends of the line, there are step-up and step-down transformers, which have the same ratio of transformation. The total equivalent resistance and reactance of the line and transformers, referred to the low-tension side, are 0.21 and 0.25 ohm at 25 cycles, respectively, per conduc-

tor. Synchronous motors, running light, but taking their full-load current, are added at the load to improve the power factor and thus increase the capacity of the generating station. Assume that the full-load efficiency of the synchronous motors and their exciters is 0.92 at unity power factor. The potential at the load is maintained constant. Induction motors operating at the same power factor as do the others are added at the load, and the synchronous motors are adjusted so that the resultant power factor of the load is increased to (*a*) 0.95, (*b*) 0.90.

For the same line current as required before the addition of the synchronous motors, calculate the permissible increase in the induction-motor load. What is the necessary kilovolt-ampere capacity of the synchronous motors? At what power factor was the generating station operating before and after the synchronous motors were added? What was the line potential at the generating station before and after the synchronous motors were added?

Synchronous-motor and Condenser Data

Number	Motors				Condensers			
	A	B	C	D	E	F	G	H
Kilovolt-amperes	80	420	960	2 000	1 000	5 000	20,000	40,000
Volts	2 200	2 300	4 600	2 200	2 300	4 000	11,000	11,500
Cycles	60	60	60	60	60	60	60	60
Connection	Y	Y	Y	2-circuit Y	Y	2-circuit Y	Y	6-circuit Y
Poles	4	6	6	4	6	10	10	12
Turns per pole	749	560	182.5	146	190.5	89.5	100.5	61.5
Diameter at air gap, inches	17.5	26.44	31	31.75	31	56	74	101
Length of core, inches	4.5	11.5	18	37	14	25	55	80
Number of slots	72	72	108	72	108	126	144	180
Series conductors per slot	32	8	8	4	5	6	3	8
Coil pitch, slots	10	10	12	13	12	11		13
Armature resistance per phase	1.36	0.219	0.444	0.0171	0.0485	0.3378	0.016	0.01775
at temperature, degrees centigrade	25	75	25	75	25	75	25	75
R_{ac}/R_{dc}	1.2	1.65	1.22	2.07	1.25	1.49	2.1	1.8
Field resistance	11.4	14.3	1.76	0.885	1.16	0.3825	0.605	0.315
at temperature, degrees centigrade	25	75	25	75	25	75	25	75
Friction and windage, kilowatts	1.90	3.6	8.00	30.9	7.00	21	110	260
Moment of inertia, pound-foot²	75		2 160		2 105		254 700	

Open-circuit Characteristics

Abscissæ, field current	Ordinates, open-circuit terminal volts							
	A[1]	B[2]	C[3]	D	E[4]	F	G	H[5]
20	......	820						
40	890	1,600	1,400	980	700	2,200	4,150	4,750
60	1,340	2,120	......	1,470	......	3,200	6,200	7,000
80	1,700	2,460	2,850	1,970	1,430	4,000	8,200	8,750
100	1,920	2,680	......	2,340	......	4,330	9,850	10,300
120	2,086	2,840	3,950	2,640	1,980	4,680	11,150	11,550
140	2,220	2,955	.....	.2,880	......	4,950	12,200	12,530
160	2,340	3,060	4,800	3,070	2,400	5,150	13,050	13,350
180	2,450	3,155	......	......	......	.5,330	13,740	14,100
200	2,550	3,240	5,380	......	2,690	5,450	14,300	14,750
220	2,640	......	......	......	......	......	14,740	
240	......	......	5,730	......	2,870	......	15,140	

Zero-power-factor Saturation Curves

Motor	Armature current	Field current when terminal volts are zero	Field current when terminal volts are rated value
A	21	5.1	13.8
B	106	6.8	16.0
C	120	32.5	84
D	475	60	157
E	251	29	72
F	722	120	250
G	1,040	176	354
H	2,005	256	575

Open-circuit Core Loss

Abscissæ core loss, kilowatts	Ordinates, open-circuit terminal volts							
	A[a]	B[b]	C	D	E	F[c]	G[d]	H[e]
4	1,320	1,310	3,300	1,100	1,650	2,200	8,500	7,350
8	1,800	1,800	4,350	1,560	2,170	2,950	11,500	9,900
12	2,050	2,170	5,000	1,840	2,500	3,400	13,240	11,500
16	2,220	2,430	5,400	2,090	2,700	3,800	14,300	12,700
20	2,350	2,630	5,680	2,270	2,840	4,100	15,050	13,600
24	2,450	2,780	5,880	2,420	2,940	4,350	......	14,330
28	2,540	......	......	2,560	......	4,550		

[1] Divide abscissæ (field current) by 20.
[2] Divide abscissæ (field current) by 10.
[3] Divide abscissæ (field current) by 4.
[4] Divide abscissæ (field current) by 5.
[5] Multiply abscissæ (field current) by 2.

[a] Divide abscissæ (core loss) by 10.
[b] Divide abscissæ (core loss) by 2.
[c] Multiply abscissæ (core loss) by 2.
[d] Multiply abscissæ (core loss) by 10.
[e] Multiply abscissæ (core loss) by 20.

CHAPTER IV

SYNCHRONOUS CONVERTER

1. The armature of a 3-phase synchronous converter has 15 slots per pole with 2 coil sides per slot. Show the arrangement of the coil sides if the coil pitch is (*a*) unity, (*b*) 14 slots.

2. The armature of a 4-phase synchronous converter has 18 slots per pole with 2 coil sides per slot. Show the arrangement of the coil sides if the coil pitch is (*a*) unity, (*b*) 17 slots.

3. The armature of a 6-phase synchronous converter has 18 slots per pole with 2 coil sides per slot. Show the arrangement of the coil sides if the coil pitch is (*a*) unity, (*b*) 17 slots.

4. Assume that the graph representing the flux density in the air gap of a synchronous converter is rectangular and is constant over the entire pole pitch. Also, assume that the armature winding is uniformly distributed and that the coil pitch is unity. Calculate the ratio of (*a*) the single-phase alternating-current potential to the direct-current potential, (*b*) the 4-phase alternating-current potential to the direct-current potential, (*c*) the 3-phase alternating-current potential to the direct-current potential, (*d*) the 6-phase alternating-current potential to the direct-current potential, (*e*) the 12-phase alternating-current potential to the direct-current potential.

5. Assume that the graph representing the flux density in the air gap of a synchronous converter is rectangular and is constant over the entire pole pitch. Also, assume that the armature winding is uniformly distributed and that the coil pitch is 0.933. Calculate the ratio of (*a*) the single-phase alternating-current potential to the direct-current potential, (*b*) the 4-phase alternating-current potential to the direct-current potential, (*c*) the 3-phase alternating-current potential to the direct-current potential, (*d*) the 6-phase alternating-current potential to the direct-current potential, (*e*) the 12-phase alternating-current potential to the direct-current potential.

6. Assume that the air-gap flux density in a synchronous converter is constant under the poles and zero between them.

The ratio of pole arc to pole pitch is (*a*) two-thirds (*b*) three-fourths. Also, assume that the armature winding is uniformly distributed and that the coil pitch is unity. Calculate the ratio of (1) the single-phase alternating-current potential to the direct-current potential, (2) the 4-phase alternating-current potential to the direct-current potential, (3) the 3-phase alternating-current potential to the direct-current potential, (4) the 6-phase alternating-current potential to the direct-current potential, (5) the 12-phase alternating-current potential to the direct-current potential.

7. Assume that the air-gap flux density in a synchronous converter is constant under the poles and zero between them. The ratio of pole arc to pole pitch is (*a*) two-thirds, (*b*) three-fourths. Assume that the armature winding is uniformly distributed and that the coil pitch is 0.933. Calculate the ratio of (1) the single-phase alternating-current potential to the direct-current potential, (2) the 4-phase alternating-current potential to the direct-current potential, (3) the 3-phase alternating-current potential to the direct-current potential, (4) the 6-phase alternating-current potential to the direct-current potential, (5) the 12-phase alternating-current potential to the direct-current potential.

8. Assume that the graph representing the flux density in the air gap of a synchronous converter is a simple-harmonic function. Assume that the armature winding is uniformly distributed and that the coil pitch is unity. Calculate the ratio of (*a*) the single-phase alternating-current potential to the direct-current potential, (*b*) the 4-phase alternating-current potential to the direct-current potential, (*c*) the 3-phase alternating-current potential to the direct-current potential, (*d*) the 6-phase alternating-current potential to the direct-current potential, (*e*) the 12-phase alternating-current potential to the direct-current potential.

9. Assume that the graph representing the flux density in the air gap of a synchronous converter is a simple-harmonic function. Assume that the armature winding is uniformly distributed and that the coil pitch is 0.933. Calculate the ratio of (*a*) the single-phase alternating-current potential to the direct-current potential, (*b*) the 4-phase alternating-current potential to the direct-current potential, (*c*) the 3-phase alternating-current potential to the direct-current potential, (*d*) the 6-phase alternating-current potential to the direct-current potential, (*e*) the 12-phase alternating-current potential to the direct-current potential.

10. Assume that the graph representing the flux distribution in the air gap of a synchronous converter is $B = B_1 \sin x + 0.3 B_1 \sin 3x$. x is the angular displacement measured from the neutral point. Assume that the armature winding is uniformly distributed and that the coil pitch is unity. Calculate the ratio of (*a*) the single-phase alternating-current potential to the direct-current potential, (*b*) the 4-phase alternating-current potential to the direct-current potential, (*c*) the 3-phase alternating-current potential to the direct-current potential, (*d*) the 6-phase alternating-current potential to the direct-current potential, (*e*) the 12-phase alternating-current potential to the direct-current potential.

11. Assume that the graph representing the flux distribution in the air gap of a synchronous converter is $B = B_1 \sin x + 0.3B_1 \sin 3x$. x is the angular displacement measured from the neutral point. Assume that the armature winding is uniformly distributed and that the coil pitch is 0.933. Calculate the ratio of (*a*) the single-phase alternating-current potential to the direct-current potential, (*b*) the 4-phase alternating-current potential to the direct-current potential, (*c*) the 3-phase alternating-current potential to the direct-current potential, (*d*) the 6-phase alternating-current potential to the direct-current potential, (*e*) the 12-phase alternating-current potential to the direct-current potential.

12. Assume that the graph representing the flux distribution in the air gap of a synchronous converter is $B = B_1 \sin x - 0.3B_1 \sin 3x$. x is the angular displacement measured from the neutral point. Assume that the armature winding is uniformly distributed and that the coil pitch is unity. Calculate the ratio of (*a*) the single-phase alternating-current potential to the direct-current potential, (*b*) the 4-phase alternating-current potential to the direct-current potential, (*c*) the 3-phase alternating-current potential to the direct-current potential, (*d*) the 6-phase alternating-current potential to the direct-current potential, (*e*) the 12-phase alternating-current potential to the direct-current potential.

13. Assume that the graph representing the flux distribution in the air gap of a synchronous converter is $B = B_1 \sin x - 0.3B_1 \sin 3x$. x is the angular displacement measured from the neutral point. Assume that the armature winding is uniformly distributed and that the coil pitch is 0.933. Calculate the ratio of (*a*) the single-phase alternating-current potential to the direct-current potential, (*b*) the 4-phase alternating-current

potential to the direct-current potential, (c) the 3-phase alternating-current potential to the direct-current potential, (d) the 6-phase alternating-current potential to the direct-current potential, (e) the 12-phase alternating-current potential to the direct-current potential.

14. Compute the ratio of the alternating- to the direct-current potential of synchronous converter A, . . . F, . . . or I when the distribution of flux in the air gap is sinusoidal and the coil pitch is (a) unity, (b) 1 slot less than the number of slots per pole. Compute the ratio when the direct-current brushes are (1) in the neutral plane, (2) shifted 10 deg. from the neutral plane.

15. Compute the ratio of the alternating- to the direct-current potential of synchronous converter A, . . . F, . . . or I when the flux density in the gap is represented by $B = B_1 \sin x + 0.2B_1 \sin 3x$ and the coil pitch is (a) unity, (b) 1 slot less than the number of slots per pole. Compute the ratio when the direct-current brushes are (1) in the neutral plane, (2) shifted 10 deg. from the neutral plane. x is the angular displacement measured from the neutral plane.

16. Compute the ratio of the alternating- to the direct-current potential of synchronous converter A, . . . F, . . . or I when the flux density in the gap is represented by $B = B_1 \sin x - 0.1B_1 \sin 3x + 0.15B_1 \sin 5x$, and the coil pitch is (a) unity, (b) 1 slot less than the number of slots per pole. Compute the ratio when the direct-current brushes are (1) in the neutral plane, (2) shifted 10 deg. from the neutral plane. x is the angular displacement measured from the neutral plane.

17. Compute the ratio of the phase to the diametrical potential of a 4-phase synchronous converter when it is assumed that the flux distribution in the air gap is sinusoidal. Assume that the armature winding is uniformly distributed and that the coil pitch is (a) unity, (b) 0.933.

18. Compute the ratio of the phase to the diametrical potential of a 4-phase synchronous converter when it is assumed that the flux density in the air gap is represented by $B = B_1 \sin x - 0.2B_1 \sin 2x + 0.12B_1 \sin 3x$. Assume that the armature winding is uniformly distributed and that the coil pitch is (a) unity, (b) 0.933.

19. Compute the ratio of the phase to the diametrical potential of a 4-phase synchronous converter when it is assumed that the

flux density in the air gap is represented by $B = B_1 \sin x - 0.1B_1 \sin 3x + 0.15B_1 \sin 5x$. Assume that the armature winding is uniformly distributed and that the coil pitch is (*a*) unity, (*b*) 0.933.

20. Compute the ratios of the 6-phase to the diametrical potential and of the 3-phase to the diametrical potential of a 6-phase synchronous converter when it is assumed that the flux distribution in the air gap is sinusoidal. Assume that the armature winding is uniformly distributed and that the coil pitch is (*a*) unity, (*b*) 0.933.

21. Compute the ratios of the 6-phase to the diametrical potential and of the 3-phase to the diametrical potential of a 6-phase synchronous converter when it is assumed that the flux density in the air gap is represented by $B = B_1 \sin x - 0.2B_1 \sin 2x + 0.12B_1 \sin 3x$. Assume that the armature winding is uniformly distributed and that the coil pitch is (*a*) unity, (*b*) 0.933.

22. Compute the ratios of the 6-phase to the diametrical potential and of the 3-phase to the diametrical potential of a 6-phase synchronous convertor when it is assumed that the flux density in the air gap is represented by $B = B_1 \sin x - 0.1B_1 \sin 3x + 0.15B_1 \sin 5x$. Assume that the armature winding is uniformly distributed and that the coil pitch is (*a*) unity, (*b*) 0.933.

23. The diametrical potential of synchronous converter B, C, D, F, G, or I is 425 volts, and its wave form is sinusoidal. Compute the 6- and the 3-phase potential. Assume that the coil pitch is (*a*) unity, (*b*) 1 slot less than the number of slots per pole.

24. The diametrical potential of synchronous converter B, C, D, F, G, or I is 425 volts, and its wave form consists of a fundamental and a 15 per cent third harmonic. Compute the 6- and the 3-phase potential. Assume that the coil pitch is (*a*) unity, (*b*) 1 slot less than the number of slots per pole.

25. The diametrical potential of synchronous converter B, C, D, F, G, or I is 425 volts, and its wave form consists of a fundamental, a 15 per cent third harmonic, and a 10 per cent fifth harmonic. Compute the 6- and the 3-phase potential. Assume that the coil pitch is (*a*) unity, (*b*) 1 slot less than the number of slots per pole.

26. The phase potential of a 4-phase synchronous converter is 300 volts, and its wave form is sinusoidal. Compute the

direct-current potential. Assume that the armature winding is uniformly distributed and that the coil pitch is (*a*) unity, (*b*) 0.933. Assume that the direct-current brushes are (*c*) in the neutral plane, (*d*) shifted 10 deg. from the neutral plane.

27. The phase potential of a 4-phase synchronous converter is 300 volts, and its wave form consists of a fundamental and a 15 per cent third harmonic which is in opposition to the fundamental. Compute the direct-current potential. Assume that the armature winding is uniformly distributed and that the coil pitch is (*a*) unity, (*b*) 0.933.

28. The phase potential of a 4-phase synchronous converter is 300 volts, and its wave form consists of a fundamental, a 15 per cent third harmonic and a 10 per cent fifth harmonic, both harmonics being in opposition to the fundamental. Compute the direct-current potential. Assume that the armature winding is uniformly distributed and that the coil pitch is (*a*) unity, (*b*) 0.933. Assume (*c*) that the direct-current brushes are in the neutral plane, (*d*) that the direct-current brushes are shifted 10 degrees from the neutral plane.

29. The phase potential of synchronous converter B, C, D, F, G, or I is 215 volts, and its wave form is sinusoidal. Compute the direct-current potential. Assume that the coil pitch is (*a*) unity, (*b*) 1 slot less than the number of slots per pole Assume that the direct-current brushes are (*c*) in the neutral plane, (*d*) shifted 10 deg. from the neutral plane.

30. The phase potential of synchronous converter B, C, D, F, G, or I is 215 volts, and its wave form consists of a fundamental and a 15 per cent third harmonic which is in opposition to the fundamental. Compute the direct-current potential. Assume that the coil pitch is (*a*) unity, (*b*) 1 slot less than the number of slots per pole. Assume that the direct-current brushes are (*c*) in the neutral plane, (*d*) shifted 10 deg. from the neutral plane.

31. The phase potential of synchronous converter B, C, D, F, G, or I is 215 volts, and its wave form consists of a fundamental, a 15 per cent third harmonic, and a 10 per cent fifth harmonic, both harmonics being in opposition to the fundamental. Compute the direct-current potential. Assume that the coil pitch is (*a*) unity, (*b*) 1 slot less than the number of slots per pole. Assume that the direct-current brushes are (*c*) in the neutral plane, (*d*) shifted 10 deg. from the neutral plane.

32. In cyclic order, the slip rings of a 6-phase synchronous converter are designated by the letters, *a b*, *c*, *d*, *e*, and *f*. The primary windings of three transformers are connected between the slip rings, *ab*, *ac*, and *ad*. The secondaries of these transformers are connected in series, and their resulting terminal potential is determined. The transformers have primary to secondary ratios of transformation of 1:2, 1:2, and 1:1, respectively. Determine the magnitude and wave form of the three possible values of the resulting secondary terminal potential of these transformers under the following conditions: The 6-phase potential is 215 volts, and its wave form (*a*) is sinusoidal, (*b*) consists of a fundamental and a 15 per cent third harmonic which is in opposition to the fundamental. (*c*) consists of a fundamental, a 15 per cent third harmonic, and a 10 per cent fifth harmonic, both harmonics being in opposition to the fundamental.

33. A 60-cycle, 4-pole, single-phase synchronous converter has 12 slots per pole with 2 coil sides per slot. Each coil has 6 turns and a coil pitch of unity. The armature is lap wound. The converter receives a sinusoidal current of 2C amp. at 78 volts and delivers a steady direct current. Neglect the rotational losses and resistance and leakage reactance of the converter. While the converter is operating at (*a*) unity power factor, (*b*) 0 866 power factor, compute the current in each coil side at the instant that the applied potential (1) is passing through zero, (2) is 0.5 of its maximum value, (3) is 0 866 of its maximum value, (4) is passing through its maximum value.

34. A single-phase, 60-cycle, 4-pole synchronous converter has 12 slots per pole with 2 coil sides per slot. Each coil has 6 turns and a coil pitch of unity. The armature is lap wound. The converter receives a sinusoidal current of 20 amp. at 78 volts and delivers a steady direct current of (*a*) 13 amp. when operating at unity power factor, (*b*) 11.25 amp. when operating at 0.866 power factor. Neglect the armature resistance and leakage reactance. Compute the torque acting on each coil side and the net torque on the armature at the instant that the applied potential (1) is passing through zero, (2) is 0.5 of its maximum value, (3) is 0.866 of its maximum value, (4) is passing through its maximum value.

35. A 3-phase, 60-cycle, 4-pole synchronous converter has 15 slots per pole with 2 coil sides per slot. Each coil has 4 turns and a coil pitch of unity. The armature is lap wound. The

converter receives a sinusoidal line current of 471 amp. at a line potential of 306 volts and delivers a steady direct current. Neglect the rotational losses and the resistance and leakage reactance of the converter. While the converter is operating at (*a*) unity power factor, (*b*) 0.866 power factor, compute the current in each coil side at the instant that the applied potential (1) is passing through zero, (2) is 0.5 of its maximum value, (3) is 0.866 of its maximum value, (4) is passing through its maximum value.

36. A 3-phase, 60-cycle, 4-pole synchronous converter has 15 slots per pole with 2 coil sides per slot. Each coil has 4 turns and a coil pitch of unity. The armature is lap wound. The converter receives a sinusoidal line current of 471 amp. at a line potential of 306 volts and delivers a steady direct current of (*a*) 475 amp. when operating at unity power factor (*b*) 410 amp. when operating at 0.866 power factor. Neglect the armature resistance and leakage reactance. Compute the torque acting on each coil side and the net torque on the armature at the instant that one of the line potentials (1) is passing through zero, (2) is 0.5 of its maximum value, (3) is 0.866 of its maximum value, (4) is passing through its maximum value.

37. A 4-phase, 60-cycle, 4-pole synchronous converter has 16 slots per pole with 2 coil sides per slot. Each coil has 4 turns and a coil pitch of unity. The armature is lap wound. The converter receives a sinusoidal line current of 353 amp. at a phase potential of 250 volts and delivers a steady direct current. Neglect the rotational losses and the resistance and leakage reactance of the converter. With the converter operating at (*a*) unity power factor, (*b*) 0.866 power factor, compute the current in each coil side at the instant that one of the phase potentials (1) is passing through zero, (2) is 0.5 of its maximum value, (3) is 0.866 of its maximum value, (4) is passing through its maximum value.

38. A 4-phase, 60-cycle, 4-pole synchronous converter has 16 slots per pole with 2 coil sides per slot. Each coil has 4 turns and a coil pitch of unity. The armature is lap wound. The converter receives a sinusoidal line current of 353 amp. at a line potential of 250 volts and delivers a steady direct current of (*a*) 475 amp. when operating at unity power factor, (*b*) 410 amp. when operating at 0.866 power factor. Neglect the armature resistance and leakage reactance Compute the torque acting on each coil side and the net torque on the armature at the instant that one of the line potentials (1) is passing through zero, (2) is 0.5 of its maxi-

mum value, (3) is 0.866 of its maximum value, (4) is passing through its maximum value.

39. Converter B, C, D, F, H, or I delivers its rated power at its rated potential and is operating at (*a*) unity power, (*b*) 0.90 power factor. Neglect all of the losses. Compute the current in each coil side at the instant that one of the phase potentials (1) is passing through zero, (2) is 0.5 of its maximum value, (3) is 0.866 of its maximum value, (4) is passing through its maximum value.

40. Converter B, C, D, F, H, or I delivers its rated power at its rated potential and is operating at (*a*) unity power factor, (*b*) 0.90 power factor. Assume that the coil pitch is unity and that, in either case, the armature efficiency is 0.97. Compute the torque acting on the conductors in each slot and the net torque on the armature at the instant the phase potential (1) is passing through zero, (2) is 0.5 of its maximum value, (3) is 0.866 of its maximum value, (4) is passing through its maximum value.

41. A 3-phase, 60-cycle, 4-pole synchronous converter has 15 slots per pole, with 2 coil sides per slot. Each coil has 4 turns and a coil pitch of unity. The armature is lap wound. This converter is operated as a double-current generator and delivers 125 kw. on the alternating-current side at (*a*) unity power factor, (*b*) 0.866 power factor and 125 kw. on the direct-current side at 500 volts. Neglect the resistance and leakage reactance of the armature. Compute the current in each coil side at the instant that the alternating-current line potential (1) is passing through zero, (2) is 0.5 of its maximum value, (3) is 0.866 of its maximum value, (4) is passing through its maximum value.

42. A 3-phase, 60-cycle, 4-pole synchronous converter has 15 slots per pole, with 2 coil sides per slot. Each coil has 4 turns and a coil pitch of unity. The armature is lap wound. This converter is operated as a double-current generator and delivers 125 kw. on the alternating-current side at (*a*) unity power factor, (*b*) 0.866 power factor and 125 kw. on the direct-current side at 500 volts. Neglect the resistance and leakage reactance of the armature. Compute the torque acting on each coil side and the net torque on the armature at the instant that the alternating-current line potential (1) is passing through zero, (2) is 0.5 of its maximum value, (3) is 0.866 of its maximum value, (4) is passing through its maximum value.

43. A 4-phase, 60-cycle, 4-pole synchronous converter has 16 slots per pole, with 2 coil sides per slot. Each coil has 4 turns and a coil pitch of unity. The armature is lap wound. This converter is operated as a double-current generator and delivers 125 kw. on the alternating current side at (*a*) unity power factor, (*b*) 0.866 power factor and, also, 125 kw. on the direct-current side at 500 volts. Neglect the resistance and leakage reactance of the armature. Compute the current in each coil side at the instant that the alternating-current phase potential (1) is passing through zero, (2) is 0.5 of its maximum value, (3) is 0.866 of its maximum value, (4) is passing through its maximum value.

44. A 4-phase, 60-cycle, 4-pole synchronous converter has 16 slots per pole, with 2 coil sides per slot. Each coil has 4 turns and a coil pitch of unity. The armature is lap wound. This converter is operated as a double-current generator and delivers 125 kw. on the alternating-current side at (*a*) unity power factor, (*b*) 0.866 power factor and 125 kw. on the direct-current side at 500 volts. Neglect the resistance and leakage reactance of the armature. Compute the torque acting on each coil side and the net torque on the armature at the instant that the alternating-current phase potential (1) is passing through zero, (2) is 0.5 of its maximum value, (3) is 0.866 of its maximum value, (4) is passing through its maximum value.

45.[1] In a single-phase synchronous converter, assume that the currents on the direct- and alternating-current sides are, respectively, steady and sinusoidal, and neglect all of the losses in calculating their relative values. Calculate the ratio of the average heating in a conductor at one of the alternating-current taps to that in a conductor midway between the taps when the converter is operating at (*a*) unity power factor, (*b*) 0.866 power factor.

46.[1] In a 4-phase synchronous converter, assume that the currents on the direct- and alternating-current sides are, respectively, steady and sinusoidal, and neglect all of the losses in calculating their relative values. Calculate the ratio of the average heating in a conductor at one of the alternating-current taps to that in a conductor midway between the taps when the converter is operating at (*a*) unity power factor, (*b*) 0.866 power factor.

[1] Assume that the resistance is independent of frequency.

47.[1] In a 3-phase synchronous converter, assume that the currents on the direct- and alternating-current sides are, respectively, steady and sinusoidal, and neglect all of the losses in calculating their relative values. Calculate the ratio of the average heating in a conductor at one of the alternating-current taps to that in a conductor midway between the taps when the converter is operating at (*a*) unity power factor, (*b*) 0.9 power factor.

48.[1] In a 6-phase synchronous converter, assume that the currents on the direct- and alternating-current sides are, respectively, steady and sinusoidal, and neglect all of the losses in calculating their relative values. Calculate the ratio of the average heating in a conductor at one of the alternating-current taps to that in a conductor midway between the taps when the converter is operating at (*a*) unity power factor, (*b*) 0.9 power factor.

49.[1] In a 12-phase synchronous converter, assume that the currents on the direct- and alternating-current sides are, respectively, steady and sinusoidal, and neglect all of the losses in calculating their relative values. Calculate the ratio of the average heating in a conductor at one of the alternating-current taps to that in a conductor midway between the taps when the converter is operating at (*a*) unity power factor, (*b*) 0.9 power factor.

50. Converter A, . . . F, . . . or I is delivering its rated direct-current output and is operating at (*a*) unity power factor, (*b*) 0.90 power factor. The coil pitch is unity. Assume that the alternating currents and potentials are sinusoidal. Assume that the armature rotational and copper losses are 3 per cent of the rated output. Compute the average heating loss per slot for slot 1, 2, 3, · · · or *n*. Slot 1 contains the first, and slot *n* contains the last coil side of one phase. Assume that the alternating- and direct-current resistances of the armature winding are the same.

51. A 3-phase, 60-cycle, 4-pole synchronous converter has 15 slots per pole with 2 coil sides per slot. Each coil has 4 turns and a coil pitch of unity. The armature is lap wound. This converter is operated as a double-current generator and delivers 125 kw. on the alternating-current side at (*a*) unity power factor, (*b*) 0.866 power factor and 125 kw. on the direct-current side at 500 volts. Neglect the resistance and leakage reactance of the armature. Compute the mean square current per slot for slot 1, 2, 3, · · · or 10. Slot 1 contains the first, and slot 10, the last coil side of one phase. The direct and alternating currents are, respectively, steady and sinusoidal.

[1] Assume that the resistance is independent of frequency.

52. A 3-phase, 60-cycle, 4-pole synchronous converter has 15 slots per pole with 2 coil sides per slot. Each coil has 4 turns and a coil pitch of unity. The armature is lap wound. This converter is operated as a double-current generator and delivers 100 kw. on the alternating-current side at (*a*) unity power factor, (*b*) 0.866 power factor and 150 kw. on the direct-current side at 500 volts. Neglect the resistance and leakage reactance of the armature. Compute the mean square current per slot for slot 1, 2, 3, · · · or 10. Slot 1 contains the first, and slot 10, the last coil side in one phase. The direct and alternating currents are, respectively, steady and sinusoidal.

53. A 4-phase, 60-cycle, 4-pole synchronous converter has 16 slots per pole with 2 coil sides per slot. Each coil has 4 turns and a coil pitch of unity. The armature is lap wound. This converter is operated as a double-current generator and delivers 125 kw. on the alternating-current side at (*a*) unity power factor, (*b*) 0.866 power factor and 125 kw. on the direct-current side at 500 volts. Neglect the resistance and leakage reactance of the armature. Compute the mean square current per slot for slot 1, 2, 3, · · · or 10. Slot 1 contains the first, and slot 10, the last coil side in one phase. The direct and alternating currents are, respectively, steady and sinusoidal.

54. A 4-phase, 60-cycle, 4-pole synchronous converter has 16 slots per pole with 2 coil sides per slot. Each coil has 4 turns and a coil pitch of unity. The armature is lap wound. The converter is operated as a double-current generator and delivers 100 kw. on the alternating-current side at (*a*) unity power factor, (*b*) 0.866 power factor and 150 kw. on the direct-current side at 500 volts. Neglect the resistance and leakage reactance of the armature. Compute the mean square current per slot for slot 1, 2, 3, · · · or 10. Slot 1 contains the first, and slot 10, the last coil side in one phase. The direct and alternating currents are, respectively, steady and sinusoidal.

55. In a single-phase synchronous converter, assume that the currents on the direct- and alternating-current sides are, respectively, steady and sinusoidal, and neglect all of the losses in calculating their relative values. (*a*) Calculate the relative outputs when operating as a synchronous converter (1) at unity power factor, (2) at 0.9 power factor and as a direct-current generator on the basis of the same armature copper loss, (*b*) Calculate the relative outputs when operating as a synchronous

converter and as a synchronous generator (1) at unity power factor, (2) at 0.9 power factor on the basis of the same armature copper loss.

56. In a 4-phase synchronous converter, assume that the currents on the direct- and alternating-current sides are, respectively, steady and sinusoidal, and neglect all of the losses in calculating their relative values. (*a*) Calculate the relative outputs when operating as a synchronous converter (1) at unity power factor, (2) at 0.9 power factor and as a direct-current generator on the basis of the same armature copper loss. (*b*) Calculate the relative outputs when operating as a synchronous converter and as a synchronous generator (1) at unity power factor, (2) at 0.866 power factor on the basis of the same armature copper loss.

57. In a 3-phase synchronous converter, assume that the currents on the direct- and alternating-current sides are, respectively, steady and sinusoidal, and neglect all of the losses in calculating their relative values. (*a*) Calculate the relative outputs when operating a synchronous converter (1) at unity power factor, (2) at 0.866 power factor and as a direct-current generator on the basis of the same armature copper loss. (*b*) Calculate the relative outputs when operating as a synchronous converter and as a synchronous generator (1) at unity power factor, (2) at 0.866 power factor on the basis of the same armature copper loss.

58. In a 6-phase synchronous converter, assume that the currents on the direct- and alternating-current sides are, respectively, steady and sinusoidal, and neglect all of the losses in calculating their relative values. (*a*) Calculate the relative outputs when operating as a synchronous converter (1) at unity power factor, (2) at 0.9 power factor and as a direct-current generator on the basis of the same armature copper loss, (*b*) Calculate the relative outputs when operating as a synchronous converter and as a synchronous generator (1) at unity power factor, (2) at 0.9 power factor on the basis of the same armature copper loss.

59. In a 12-phase synchronous converter, assume that the currents on the direct- and alternating-current sides are, respectively, steady and sinusoidal, and neglect all of the losses in calculating their relative values. (*a*) Calculate the relative outputs when operating as a synchronous converter at unity power factor, (2) at 0.866 power factor and as a direct-current generator on the basis of the same armature copper loss. (*b*) Calculate the relative outputs when operating as a synchronous

converter and as a synchronous generator (1) at unity power factor, (2) at 0.866 power factor on the basis of the same armature copper loss.

60. A 3-phase, 60-cycle, 4-pole synchronous converter has 15 slots per pole with 2 coil sides per slot. Each coil has 4 turns and a coil pitch of unity. The armature is lap wound. When this converter is operated as a direct-current generator, it has a rated capacity of 250 kw. at 500 volts. (Assume that this excitation is maintained constant.) On the basis of the same armature heating loss, what will be its rated capacity when operated as (*a*) a synchronous generator at (1) unity power factor, (2) 0.80 power factor, (*b*) a synchronous converter at (1) unity power factor, (2) 0.90 power factor (assume that the armature efficiency is 0.97), (*c*) a double-current generator with equal outputs on the direct- and alternating-current sides and at a power factor of (1) unity, (2) 0.90 (assume that the load on the alternating-current side is balanced), (*d*) a double-current generator with a direct-current output 50 per cent greater than the alternating-current output and at a power factor of (1) unity, (2) 0.90 (assume that the load on the alternating-current side is balanced)?

61. A 3-phase, 60-cycle, 4-pole synchronous converter has 15 slots per pole, with 2 coil sides per slot. Each coil has 4 turns and a coil pitch of unity. The armature is lap wound. When this converter is operated as a direct-current generator, it has a rated capacity of 250 kw. at 500 volts. (Assume that this excitation is maintained constant.) On the basis of the same armature heating losses, what additional alternating-current output can it deliver at (*a*) unity power factor, (*b*) 0.90 power factor when it is delivering (1) 100 kw., (2) 150 kw. on the direct-current side?

62. A 4-phase, 60-cycle, 4-pole synchronous converter has 16 slots per pole, with 2 coil sides per slot. Each coil has 4 turns and a coil pitch of unity. The armature is lap wound. When this converter is operated as a direct-current generator, it has a rated capacity of 250 kw. at 500 volts. (Assume that this excitation is maintained constant.) On the basis of the same armature heating loss, what will be its rated capacity when operated as (*a*) a synchronous generator at (1) unity power factor, (2) 0.80 power factor, (*b*) a synchronous converter at (1) unity power factor, (2) 0.90 power factor (assume that the armature efficiency

s 0.97), (*c*) a double-current generator with equal outputs on the lirect- and alternating-current sides and at a power factor of (1) ınity, (2) 0.90 (assume that the load on the alternating-current side is balanced), (*d*) a double-current generator with a direct-current output 50 per cent greater than the alternating-current output and at a power factor of (1) unity, (2) 0.90 (assume that the load on the alternating-current side is balanced)?

63. A 4-phase, 60-cycle, 4-pole synchronous converter has 16 slots per pole, with 2 coil sides per slot. Each coil has 4 turns and a coil pitch of unity. The armature is lap wound. When this converter is operated as a direct-current generator, it has a rated capacity of 250 kw. at 500 volts. (Assume that this excitation is maintained constant.) On the basis of the same armature heating losses, what additional alternating-current output can it deliver at (*a*) unity power factor, (*b*) 0.90 power factor when it is delivering (1) 100 kw., (2) 150 kw. on the direct-current side?

64. (*a*) A 3-phase, 60-cycle, 4-pole synchronous converter has 15 slots per pole with 2 coil sides per slot. Each coil has 4 turns and a coil pitch of unity. The armature is lap wound. This converter is operating at unity power factor and is delivering 250 kw. at 500 volts on the direct-current side. Assume that the total armature losses are 3 per cent of the output and that the direct-current brushes are in the neutral plane. Use a scale of 5000 ampere-turns equal 1 in. Plot the component distributions of m.m.f. acting on the air gap due to (1) the direct current, (2) the active component of the alternating current, (3) the reactive component of the alternating current at the moment that the alternating current in one phase (*a*) is passing through zero, (*b*) is 0.5 of its maximum value, (*c*) is 0.866 of its maximum value, (*d*) is passing through its maximum value.

(*b*) This converter is operated as a double-current generator and delivers 125 kw. at unity power factor on the alternating-current side and 125 kw. at 500 volts on the direct-current side. Assume that the direct-current brushes are in the neutral plane. Plot the distributions of m.m.f. that are required under part (*a*). Use a scale of 5000 ampere-turns equal 1 inch.

65. (*a*) A 3-phase, 60-cycle, 4-pole synchronous converter has 15 slots per pole, with 2 coil sides per slot. Each coil has 4 turns and a coil pitch of unity. The armature is lap wound. This converter is operating at 0.866 power factor (lagging) and is delivering 250 kw. at 500 volts on the direct-current side.

Assume that the total armature losses are 3 per cent of the output and that the direct-current brushes are in the neutral plane. Use a scale of 5000 ampere-turns equal 1 in. Plot the component distributions of m.m.f. acting on the air gap due to (1) the direct current, (2) the active component of the alternating current, (3) the reactive component of the alternating current at the moment that the alternating current in one phase (*a*) is passing through zero, (*b*) is 0.5 of its maximum value, (*c*) is 0.866 of its maximum value, (*d*) is passing through its maximum value.

(*b*) This converter is operated as a double-current generator and delivers 125 kw. at 0.866 power factor (lagging) on the alternating-current side and 125 kw. at 500 volts on the direct-current side. Assume that the direct-current brushes are in the neutral plane. Plot the distributions of m.m.f. that are required under part (*a*). Use a scale of 5000 ampere-turns equal 1 in.

66. (*a*) A 3-phase, 60-cycle, 4-pole synchronous converter has 15 slots per pole with 2 coil sides per slot. Each coil has 4 turns and a coil pitch of unity. The armature is lap wound. This converter is operating at 0.866 power factor (leading) and is delivering 250 kw. at 500 volts on the direct-current side. Assume that the total armature losses are 3 per cent of the output and that the direct-current brushes are in the neutral plane. Use a scale of 5000 ampere-turns equal 1 in. Plot the component distributions of m.m.f. acting on the air gap due to (1) the direct current, (2) the active component of the alternating current, (3) the reactive component of the alternating current at the moment that the alternating current in one phase (*a*) is passing through zero, (*b*) is 0.5 of its maximum value, (*c*) is 0.866 of its maximum value, (*d*) is passing through its maximum value.

(*b*) This converter is operated as a double-current generator and delivers 125 kw. at 0.866 power factor (leading) on the alternating-current side and 125 kw. at 500 volts on the direct-current side. Assume that the direct-current brushes are in the neutral plane. Plot the distributions of m.m.f. that are required under part (*a*). Use a scale of 5000 ampere-turns equal 1 in.

67. (*a*) A 4-phase, 60-cycle, 4-pole synchronous converter has 16 slots per pole with 2 coil sides per slot. Each coil has 4 turns and a coil pitch of unity. The armature is lap wound. This converter is operating at unity power factor and is delivering 250 kw. at 500 volts on the direct-current side. Assume that the total armature losses are 3 per cent of the output and that the

direct-current brushes are in the neutral plane. Use a scale of 5000 ampere-turns equal 1 in. Plot the component distributions of m.m.f. acting on the air gap due to (1) the direct current, (2) the active component of the alternating current, (3) the reactive component of the alternating current at the moment that the alternating current in one phase (*a*) is passing through zero, (*b*) is 0.5 of its maximum value, (*c*) is 0.866 of its maximum value, (*d*) is passing through its maximum value.

(*b*) This converter is operated as a double-current generator and delivers 125 kw. at unity power factor on the alternating-current side and 125 kw. at 500 volts on the direct-current side. Assume that the direct-current brushes are in the neutral plane. Plot the distributions of m.m.f. that are required under part (*a*). Use a scale of 5000 ampere-turns equal 1 in.

68. (*a*) A 4-phase, 60-cycle, 4-pole synchronous converter has 16 slots per pole with 2 coil sides per slot. Each coil has 4 turns and a coil pitch of unity. The armature is lap wound. This converter is operating at 0.866 power factor (lagging) and is delivering 250 kw. at 500 volts on the direct-current side. Assume that the total armature losses are 3 per cent of the output and that the direct-current brushes are in the neutral plane. Use a scale of 5000 ampere-turns equal 1 in. Plot the component distributions of m.m.f. acting on the air gap due to (1) the direct current, (2) the active component of the alternating current, (3) the reactive component of the alternating current at the moment that the alternating current in one phase (*a*) is passing through zero, (*b*) is 0.5 of its maximum value, (*c*) is 0.866 of its maximum value, (*d*) is passing through its maximum value.

(*b*) This converter is operated as a double-current generator and delivers 125 kw. at 0.866 power factor (lagging) on the alternating-current side and 125 kw. at 500 volts on the direct-current side. Assume that the direct-current brushes are in the neutral plane. Plot the distributions of m.m.f. that are required under part (*a*). Use a scale of 5000 ampere-turns equal 1 in.

69. (*a*) A 4-phase, 60-cycle, 4-pole synchronous converter has 16 slots per pole, with 2 coil sides per slot. Each coil has 4 turns and a coil pitch of unity. The armature is lap wound. This converter is operating at 0.866 power factor (leading) and is delivering 250 kw. at 500 volts on the direct-current side.

Assume that the total armature losses are 3 per cent of the output and that the direct-current brushes are in the neutral plane. Use a scale of 5000 ampere-turns equal 1 in. Plot the component distributions of m.m.f. acting on the air gap due to (1) the direct current, (2) the active component of the alternating current, (3) the reactive component of the alternating current at the moment that the alternating current in one phase (*a*) is passing through zero, (*b*) is 0.5 of its maximum value, (*c*) is 0.866 of its maximum value, (*d*) is passing through its maximum value.

(*b*) This converter is operated as a double-current generator and delivers 12 kw. at 0.866 power factor (leading) on the alternating-current side and 125 kw. at 500 volts on the direct-current side. Assume that the direct-current brushes are in the neutral plane. Plot the distributions of m.m.f. that are required under part (*a*). Use a scale of 5000 ampere-turns equal 1 in.

70. A 6-phase, 60-cycle, 4-pole synchronous converter has 15 slots per pole, with 2 coil sides per slot. Each coil has 4 turns and a coil pitch of unity. The armature is lap wound. This converter is operating at unity power factor and is delivering 250 kw. at 500 volts on the direct-current side. Assume that the total armature losses are 3 per cent of the output and that the direct-current brushes are in the neutral plane. Use a scale of 5000 ampere-turns equal 1 in. Plot the component distributions of m.m.f. acting on the air gap due to (1) the direct current, (2) the active component of the alternating current, (3) the reactive component of the alternating current at the moment that the alternating current in one phase (*a*) is passing through zero, (*b*) is 0.5 of its maximum value, (*c*) is 0.866 of its maximum value, (*d*) is passing through its maximum value.

71. A 6-phase, 60-cycle, 4-pole synchronous converter has 15 slots per pole, with 2 coil sides per slot. Each coil has 4 turns and a coil pitch of unity. The armature is lap wound. This converter is operating at 0.90 power factor (lagging) and is delivering 250 kw. at 500 volts on the direct-current side. Assume that the total armature losses are 3 per cent of the output and that the direct-current brushes are in the neutral plane. Use a scale of 5000 ampere-turns equal 1 in. Plot the component distributions of m.m.f. acting on the air gap

due to (1) the direct current, (2) the active component of the alternating current, (3) the reactive component of the alternating current at the moment that the alternating current in one phase (*a*) is passing through zero, (*b*) is 0.5 of its maximum value, (*c*) is 0.866 of its maximum value, (*d*) is passing through its maximum value.

72. A 6-phase, 60-cycle, 4-pole synchronous converter has 15 slots per pole, with 2 coil sides per slot. Each coil has 4 turns and a coil pitch of unity. The armature is lap wound. This converter is operating at 0.90 power factor (leading) and is delivering 250 kw. at 500 volts on the direct-current side. Assume that the total armature losses are 3 per cent of the output and that the direct-current brushes are in the neutral plane. Use a scale of 5000 ampere-turns equal 1 in. Plot the component distributions of m.m.f. acting on the air gap due to (1) the direct current, (2) the active component of the alternating current, (3) the reactive component of the alternating current at the moment that the alternating current is one phase (*a*) is passing through zero, (*b*) is 0.5 of its maximum value, (*c*) is 0. 866 of its maximum value, (*d*) is passing through its maximum value.

73. A 5-kw. single-phase synchronous converter supplies power on the direct-current side at 110 volts. It receives energy on the alternating-current side through a transformer from a 2200-volt circuit. What should be the transformer's ratio of transformation? If the converter has an efficiency of 85 per cent, what should be the current rating of the high-tension winding of the transformer?

74. A 100-kw., 4-phase synchronous converter supplies power on the direct-current side through two single-phase transformers from a 2-phase circuit. The potential between adjacent high-tension conductors is 1555 volts and between alternate conductors is 2200 volts. The high-tension windings of the transformers are connected across the 2200-volt lines, and the low-tension windings are connected in star with the neutral point grounded. The efficiency of the converter at full load and unity power factor is 94 per cent. What should be the full-load current and potential ratings of the high- and low-tension windings of the transformers?

75. A 4-phase, 50-kw. synchronous converter supplies powei on the direct-current side at 220 volts. It receives energy on

the alternating-current side from a 2-phase line through two single-phase transformers which have double primary and secondary windings. The potential between the adjacent high-tension conductors is 1625 volts and between alternate conductors is 2300 volts. The high-tension windings of the transformers are connected in star, and the low-tension windings in mesh. The efficiency of the converter at full-load output and 0.90 power factor is 90.2 per cent. What are the primary and secondary currents and potentials when the converter delivers its rated load and operates at 0.90 power factor?

76. A 4-phase 100-kw. synchronous converter delivers power on the direct-current side at 220 volts. It receives energy from a 3-phase, 11,000-volt circuit through Scott-connected transformers. The low-tension windings are connected in star. The efficiency of the converter at full load and unity power factor is 92.5 per cent. What are the ratios of transformation of each of the transformers? What are the full-load current ratings of the primary and secondary windings of each transformer?

77. A 4-phase, 100-kw., 230-volt synchronous converter receives its power from a 3-phase, 6600-volt circuit through Scott-connected transformers. The low-tension windings are double and are connected in mesh. The efficiency of the converter at full load and 0.90 power factor is 91 8 per cent. What are the high- and low-tension currents and potentials of the transformers when the converter delivers its rated load and operates at 0.90 power factor?

78. A 3-phase, 200-kw. synchronous converter supplies direct current at 110 volts. It receives power from a 3-phase, 6600-volt circuit through 3 single-phase transformers which have their high-tension windings connected in Δ and their low-tension windings connected in Y. At full load and unity power factor, the converter has an efficiency of 93 per cent. What should be the full-load current and potential ratings of the high- and low-tension windings of the transformers?

79. A 3-phase, 250-kw., 220-volt synchronous converter receives power through 3 single-phase transformers from a 3-phase, 2200-volt circuit. The high-tension windings of the transformers are connected in Y, and the low-tension windings in Δ. The converter has an overload current capacity of 15 per cent when operating at 0.9 power factor, and at this time the

efficiency is 91.8 per cent. What should be the overload current and potential ratings of the high- and low-tension windings of the transformers?

80. A 3-phase, 300-kw., 500-volt synchronous converter receives power through 3 single-phase transformers from a 3-phase, 11,000-volt circuit. Both the high- and low-tension windings of the transformers are connected in Y. When delivering its rated load and operating at 0.85 power factor, the conveter has an efficiency of 91.6 per cent. What is the ratio of transformation of the transformers? What should be the full-load current ratings of the high- and low-tension windings of the transformers?

81. A 3-phase, 150-kw., 230-volt synchronous converter receives power through 2 single-phase transformers from a 3-phase, 2200-volt circuit. Both the primary and secondary windings of the transformers are connected in V. Neglecting the losses, what should be the current and potential ratings of the high- and low-tension windings of the transformers?

82. A 6-phase, 1500-kw., 650-volt synchronous converter delivers power to a railway system. It receives power through 3 single-phase transformers from a 3-phase, 13,200-volt transmission line. The transformers are connected in Y on the high-tension side and diametrically on the low-tension side. In order to maintain a constant line potential of 13,200 volts at the substation, the converter is overcompounded so that when delivering 10 per cent overload current at 650 volts it operates at 0.95 power factor with an efficiency of 92.7 per cent. What is the ratio of transformation for each transformer? What should be the overload current ratings of the high- and low-tension windings of the transformers?

83. A 6-phase, 1000-kw., synchronous converter receives power through 3 transformers from a 3-phase, 11,000-volt circuit. The converter delivers power at 650 volts to a railway system. The transformers are connected in Y on the high-tension and in double-Δ on the low-tension side. What should be the current and potential ratings and the ratio of transformation for each of these transformers? In determining the rating, neglect the losses.

84. A 6-phase, 2000-kw., synchronous converter receives power from a 3-phase, 13,000-volt transmission line. The transformers are connected in Δ on the high-tension and in

double Y on the low-tension side. The converter delivers power at 650 volts to a railway system. It has an overload current capacity of 10 per cent and an efficiency of 92.8 per cent when delivering this load and operating at 0.95 power factor. What should be the overload current and potential ratings of the high- and low-tension windings of the transformers? What should be their ratio of transformation?

85. The synchronous converter B, C, D, F, H, or I receives its power from a 13,200-volt circuit and, while operating at 0.95 power factor, delivers its rated load on the direct-current side. It may be assumed that the efficiency of the converter is 0.95 at this time. (*a*) If the transformers are connected in Δ-YY, what should be the current and potential rating of each transformer winding? (*b*) If the converter is operated 3-phase, with the transformers connected in Δ-Y, what should be the current and potential rating of each transformer winding? In this case, the converter is also operated at 0.95 power factor and with an output as great as possible without exceeding the armature copper loss obtained when operating 6-phase at the same power factor and its rated output.

86. The synchronous converter B, C, D, F, H, or I receives its power from a 13,200-volt circuit and, while operating at 0.95 power factor, delivers its rated load on the direct-current side. It may be assumed that the efficiency of the converter is 0.95 at this time. (*a*) If the transformers are connected in Y-YY, what should be the current and potential rating of each transformer winding? (*b*) If the converter is operated 3-phase, with the transformers connected in Y-Y, what should be the current and potential rating of each transformer winding? In this case, the converter is also operated at 0.95 power factor and with an output as great as possible without exceeding the armature copper loss obtained when operating 6-phase at the same power factor and its rated output.

87. A synchronous converter B, C, D, F, H, or I receives its power from a 13,200-volt circuit and, while operating at 0.95 power factor, delivers its rated load on the direct-current side. It may be assumed that the efficiency of the converter is 0.95 at this time. (*a*) If the transformers are connected in Δ-Δ∇, what should be the current and potential rating of each transformer winding? (*b*) If the converter is operated 3-phase, with the transformers connected in Δ-Δ, what should be the current

and potential rating of each transformer winding? In this case, the converter is also operated at 0.95 power factor and with an output as great as possible without exceeding the armature copper loss obtained when operating 6-phase at the same power factor and its rated output.

88. The synchronous converter B, C, D, F, H, or I receives its power from a 13,200-volt circuit and, while operating at 0.95 power factor, delivers its rated load on the direct-current side. It may be assumed that the efficiency of the converter is 0.95 at this time. (*a*) If the transformers are connected in Y-Δ∇, what should be the current and potential rating of each transformer winding? (*b*) If the converter is operated 3-phase, with the transformers connected in Y-Δ, what should be the current and potential rating of each transformer winding? In this case, the converter is also operated at 0.95 power factor and with an output as great as possible without exceeding the armature copper loss obtained when operating 6-phase at the same power factor and its rated output.

89. The synchronous converter B, C, D, F, H, or I receives its power from a 13,200-volt circuit and, while operating at 0.95 power factor, delivers its rated load on the direct-current side. It may be assumed that the efficiency of the converter is 0.95 at this time. If the transformers are connected in V-VΛ, what should be the current and potential rating of each transformer winding?

90. The synchronous converter B, C, D, F, H, or I receives its power from a 13,200-volt circuit and, while operating at unity power factor, delivers its rated load on the direct-current side. The primary windings of the transformers are connected in Y. If the slip rings, taken in cyclic order, are designated by *a*, *b*, *c*, *d*, *e*, and *f*, the secondary windings of the three transformers are connected, respectively, to *ab*, *cd*, and *ef*. Assume that the efficiency of the converter at this time is 0.95. What should be the current and potential ratings of each transformer winding?

91. The synchronous converter B, C, D, F, H, or I receives its power from a 13,200-volt circuit and, while operating at unity power factor, delivers its rated load on the direct-current side. The primary windings of the transformers are connected in Δ. If the slip rings, taken in cyclic order, are designated by *a*, *b*, *c*, *d*, *e*, and *f*, the secondary windings of the 3 transformers are connected, respectively, to *ab*, *cd*, and *ef*. Assume that the efficiency

of the converter at this time is 0.95. What should be the current and potential ratings of each transformer winding?

92. A 12-phase, 3000-kw., 650-volt synchronous converter receives power from a 3-phase transmission line through 3 single-phase transformers whose high-tension windings are connected in Y and whose low-tension windings are connected in double chord. The high-tension line potential is 22,000 volts. Neglecting the losses, what should be the current and potential ratings of the high- and low-tension windings of the transformers?

93.[1] If the currents in the primary windings of the transformers supplying a synchronous converter are balanced, and if the ratios of transformation of the transformers are alike, show that the alternating components of the phase currents in the armature of the converter are also balanced when the transformers are connected with (*a*) primaries in Δ, secondaries in Δ; (*b*) primaries in Δ, secondaries in Y; (*c*) primaries in Y, secondaries in Δ; (*d*) primaries in Y, secondaries in Y; (*e*) primaries in Δ, secondaries in YY; (*f*) primaries in Δ, secondaries in Δ∇; (*g*) primaries in Y, secondaries in YY; (*h*) primaries in Y, secondaries in Δ∇; (*i*) primaries in Δ, secondaries in diametrical; (*j*) primaries in Y, secondaries in diametrical; (*k*) primaries in 2-phase, secondaries in 4-phase, star; (*l*) primaries in 2-phase, secondaries in 4-phase, mesh.

94.[1] A 4-phase synchronous converter can be supplied with single-phase power either as shown in Fig. 11 or as shown in

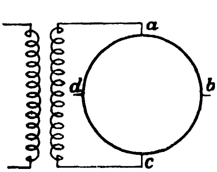


FIG. 11.

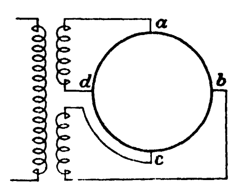


FIG. 12.

Fig. 12. The slip rings are designated by *a*, *b*, *c*, etc. In each case, the transformers have the proper ratio of transformation to give the same direct-current potential. (*a*) Determine the relative magnitudes of the alternating components of the currents in each portion of the armature windings when the outputs are

[1] If the armature winding is properly arranged, the vector sum of the phase currents taken in cyclic order is zero. This is, in general, true even if there are harmonics, in which case the statement holds for the currents of each harmonic frequency

equal. (*b*) Compare the outputs of the converter for the same armature heating and a power factor of (1) unity, (2) 0.866.

95. A 6-phase synchronous converter can be supplied with single-phase power either as shown in Figs. 13 and 14 or as shown in Fig. 15. The slip rings are designated by *a*, *b*, *c*, etc. In each case, the transformers have the proper ratio transforma-

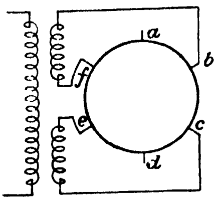


Fig. 13.

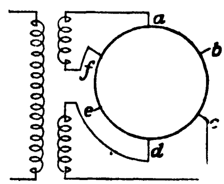


Fig. 14.

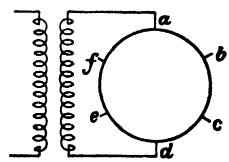


Fig. 15.

tion to give the same direct-current potential. (*a*) Determine the relative magnitudes of the alternating components of the currents in each portion of the armature winding when the outputs are equal. (*b*) Compare the outputs of the converter for the same armature heating and a power factor of (1) unity, (2) 0.866.

96.[1] A 6-phase synchronous converter can be supplied with 4-phase power from a 2-phase circuit, as shown in Fig. 16, or the armature winding can be tapped at additional points, as indicated

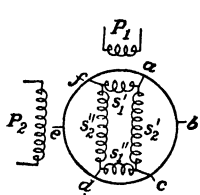


Fig. 16.

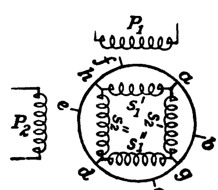


Fig. 17.

in Fig. 17, and balanced 4-phase power can be supplied from the 2-phase circuit. The slip rings are designated by *a*, *b*, *c*, etc. In each case, assume that the transformers are so adjusted that the power taken from the 2-phase circuit is balanced and the direct-current potentials of the converter are equal. (*a*) Determine the relative magnitudes and phase relations of the alternating components of the currents in each portion of the armature

[1] If the armature winding is properly arranged, the vector sum of the phase currents taken in cyclic order is zero. This is, in general, true even if there are harmonics, in which case the statement holds for the currents of each harmonic frequency.

winding when the outputs are equal. (*b*) Compare the outputs of the converter for the same armature heating and a power factor of (1) unity, (2) 0.866.

97.[1] A 6-phase synchronous converter can be supplied with balanced 3-phase power from a 3-phase circuit, as shown in Fig. 18 or in Fig. 19. The slip rings are designated by *a*, *b*, *c*, etc. In each case, the transformers are adjusted so that the direct-

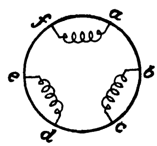


FIG. 18.

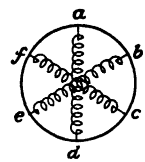


FIG. 19.

current potentials of the converter are equal. (*a*) Determine the relative magnitudes and phase relations of the alternating components of the currents in each portion of the armature winding when the outputs are equal. (*b*) Compare the outputs for the same armature heating and a power factor of (1) unity, (2) 0.866.

98.[1] A 6-phase synchronous converter is supplied with power from a balanced 3-phase circuit through transformers which are connected in Δ on the primary side and in 6-phase mesh on the secondary side. It becomes necessary to remove one of the transformers. Assume that when this is done the relative phase relation of the currents in the primary windings of the two remaining transformers is unaltered. (*a*) Determine the relative magnitudes and phase relations of the alternating components of the currents in each portion of the armature winding, before and after the transformer is removed, when the outputs are equal. (*b*) Compare the outputs for the same armature heating, before and after the transformer is removed, when the power factor is (1) unity, (2) 0.90.

99.[1] A 6-phase synchronous converter is supplied with power from a balanced 3-phase circuit through transformers which are connected in Δ on the primary side and in double-Δ on the secondary side. It becomes necessary to remove one of the transformers. Assume that when this is done, the relative phase

[1] If the armature winding is properly arranged, the vector sum of the phase currents taken in cyclic order is zero. This is, in general, true even if there are harmonics, in which case the statement holds for the currents of each harmonic frequency.

relation of the currents in the primary windings of the two remaining transformers is unaltered. (*a*) Determine the relative magnitudes and phase relations of the alternating components of the currents in each portion of the armature winding, before and after the transformer is removed, when the outputs are equal. (*b*) Compare the outputs for the same armature heating, before and after the transformer is removed, when the power factor is (1) unity, (2) 0.90.

100. A 6-phase synchronous converter is supplied with power from a 2-phase circuit, as shown in Fig. 20. The slip rings are designated by *a*, *b*, *c*, etc. The transformers are adjusted so that the power taken from the 2-phase circuit is balanced. (*a*) Determine the relative magnitudes and phase relations of the alternating components of the currents in each portion of the armature winding. (*b*) Compare the output of this converter, on the basis of the same armature heating loss, with what it would be if supplied with balanced 6-phase power from a 3-phase circuit when the power factor is (1) unity, (2) 0.90, and the direct-current potentials are equal.

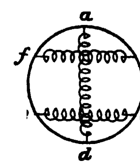


FIG. 20.

101. A 12-phase synchronous converter is supplied with balanced power from a 3-phase circuit through transformers which are connected in double-chord on the secondary side. (*a*) Determine the relative magnitudes and phase relations of the alternating components of the currents in each portion of the armature winding. (*b*) Compare the output of this converter, on the basis of the same armature heating loss, with what it would be if supplied with balanced 12-phase power at the slip rings when the power factor is (1) unity, (2) 0.95, and the direct-current potentials are equal.

102.[1] A 3-phase, 25-cycle synchronous converter has a full-load capacity of 300 kw. at 600 volts. The armature has 96 slots, with 6 inductors in series per slot. The field structure has 4 poles. Neglect the resistance and leakage reactance of the armature winding. When this converter receives a line current of 540 amp. at 367 volts and is overexcited so that it operates at a

[1] In calculating the armature reaction, do not neglect the distribution of the winding, and assume that the constant usually given as 0.707 is 0.75. This makes an approximate correction for the effect of the ratio of pole arc to pole pitch.

power factor of 0.90, what are the demagnetizing ampere-turns per pole?

103.[1] A 6-phase, 25-cycle, 600-volt synchronous converter has an efficiency of 92.5 per cent when delivering 750 kw. and operating at 0.90 power factor. There are 8 poles. The armature winding has 4 inductors in series per slot and 24 slots per pole. Neglect the resistance and the leakage reactance of the armature winding. What are the demagnetizing ampere-turns per pole for the specified load?

104. What are the magnetizing ampere-turns per pole of synchronous converter A, . . . E, . . . or I when it delivers its rated output on the direct-current side and operates at a power factor of 0.95?

105. A shunt-wound synchronous converter operates from a constant-potential alternating-current circuit without any adjustment of the shunt-field circuit. At three-quarters of full load on the direct-current side, the power factor is 0.95. What will be the power factor if the converter delivers one and one-quarter of full load?

106. A synchronous converter is operating from a constant-potential alternating-current system and delivers its rated full load at 600 volts. With the shunt-field rheostat cut out, the field current is 7.8 amp., and the power factor is 0.95. With a field current of 6.0 amp., the power factor is unity. How much should be the resistance of the rheostat in order that the power factor may be reduced to 0.93?

107. When delivering full load and operating at unity power factor, the necessary field excitation of a synchronous converter is 11.2 amp. For the same load but a power factor of 0 9 (lagging), the field current is 8.8 amp. What is the necessary field current when delivering full load and operating at a power factor of 0.95 (leading)?

108. A 300-kw., 3-phase, synchronous converter is rated to deliver power at 110 volts. The alternating-current line potential is 2200 volts. Write the current and potential specifications for the transformers which you would order. It is observed that when this converter delivers its rated load at rated potential, the

[1] In calculating, the armature reaction, do not neglect the distribution of the winding, and assume that the constant usually given as 0 707 is 0.75. This makes an approximate correction for the effect of the ratio of pole arc to pole pitch.

power factor is unity for a shunt-field current of 4.1 amp. and 0.90 when the field current is 3.3 amp. At what power factor will it operate when delivering its rated load if the field current is 4.6 amp.?

109. A 3-phase, 25-cycle synchronous converter has a full-load capacity of 300 kw. at 600 volts. The armature has 96 slots with 6 inductors in series per slot. The field structure has 4 poles with 2340 turns in the shunt winding per pole. The resistance of this field circuit with all of the regulating rheostat cut out is 120.5 ohms. A current of 3.25 amp. in the shunt-field winding alone gives the normal excitation, *i.e.*, for full load at unity power factor. In order to maintain the terminal potential on the direct-current side at 600 volts when full load is delivered, it is necessary to overexcite the converter so that it takes a line current of 600 amp. at a power factor of 86 per cent. Calculate the least number of series field turns that must be added in order that this excitation may be produced. What should be the current in the shunt-field winding?

110. A 3-phase, 25-cycle synchronous converter has a full-load capacity of 300 kw. at 600 volts. The armature has 96 slots with 6 inductors per slot. The field structure has 4 poles with 2340 turns per pole. The resistance of this field circuit with all of the regulating rheostat cut out is 120 ohms. A field current of 3.25 amp. gives normal excitation, *i.e.*, for full load at unity power factor and a direct-current potential of 600 volts. When the converter delivers full load at 600 volts, what is the lowest power factor (leading) at which it can be operated? Assume that the efficiency of the converter at this time is 94 per cent.

111.[1] A 6-phase, 60-cycle, 600-volt synchronous converter has a full-load capacity of 1000 kw. when operating at unity power factor. The armature has 180 slots with 6 inductors in series per slot. The field structure has 12 poles each of which is wound with 864 turns. When this converter is overexcited so that it operates at 0.95 power factor and is delivering its rated output on the direct-current side, the efficiency is 92.9 per cent. How much greater is the field current than its normal value, *i.e.*, if the power factor were unity?

[1] In calculating the armature reaction, do not neglect the distribution of the winding, and assume that the constant usually given as 0.707 is 0.75. This makes an approximate correction for the effect of the ratio of pole arc to pole pitch

112.[1] At full load and when operating at unity power factor, a 3-phase, 25-cycle synchronous converter receives a line current of 499 amp. at 367 volts and delivers on the direct-current side 500 amp. at 600 volts. The armature has 96 slots with 6 inductors in series per slot. The field structure has 4 poles with 2340 turns in the shunt windings per pole. The resistance of this field circuit with the regulating rheostat cut out is 120.5 ohms. When this converter receives its rated current, what is the least power factor at which it can be operated and still maintain its rated potential? The normal excitation, *i.e.*, when operating at unity power factor is 3.25 amp.

113.[1] At full load and when operating at unity power factor, a 6-phase, 25-cycle compound synchronous converter receives a line current of 840 amp. at a potential of 212 volts between adjacent slip rings and delivers on the direct-current side 1667 amp. at 600 volts. The armature has 168 slots with 6 inductors in series per slot. The field structure has 8 poles with 1501 turns in the shunt winding and 2 turns in the series winding per pole. A current of 5.6 amp. in the shunt-field winding alone is the normal excitation and produces a potential of 600 volts on the direct-current side at no load when running as a generator. When this converter delivers 1500 amp. at 600 volts, what should be the shunt-field current in order that the current on the alternating-current side shall be leading and not exceed its full-load value and the power factor have its least value? What is this power factor? Neglect any change in the efficiency.

114.[1] At full load and when operating at unity power factor, a 6-phase, 60-cycle synchronous converter receives a line current of 840 amp. at a potential of 424 volts between diametrical points of the armature and delivers on the direct-current side a current of 1667 amp. at 600 volts. The armature has 15 slots per pole with 6 inductors in series per slot. There are 12 field poles, on each of which there are 864 turns in the shunt winding and 2 turns in the series winding. A current of 9.3 amp. in the shunt-field winding alone is the excitation which produces a potential of 600 volts on the direct-current side at no load when running as a generator. When this converter delivers 1460 amp. at 600 volts,

[1] In calculating the armature reaction, do not neglect the distribution of the winding, and assume that the constant usually given as 0.707 is 0.75. This makes an approximate correction for the effect of the ratio of pole arc to pole pitch.

what are the limits of the shunt-field current in order that the current on the alternating-current side shall not exceed its full-load value and the power factor have its least value? What are these limiting power factors? Neglect any change in the efficiency.

115.[1] At full load and when operating at unity power factor, a 6-phase, 25-cycle synchronous converter takes a line current of 840 amp. at a potential of 424 volts between diametrical points and delivers 1667 amp. at 600 volts. The armature has 21 slots per pole with 6 inductors in series per slot. There are 8 field poles each of which is wound with 1501 turns. The resistance of the field circuit with the regulating rheostat cut out is 76.6 ohms. A current of 5.6 amp. in the field winding is the normal excitation, *i.e.*, for full load and unity power factor. With an output of 850 kw. at 600 volts, what is the least power factor at which this converter can be operated when overexcited? What per cent is the current on the alternating-current side of its full-load value? Neglect any change in the efficiency.

116.[1] At full load and when operating at unity power factor, a 6-phase, 60-cycle synchronous converter takes a line current of 840 amp. at 212 volts per phase and delivers 1000 kw. at 600 volts. The armature has 18 slots per pole with 6 inductors in series per slot. The field structure has 12 poles with 864 turns in the shunt winding and 2 turns in the series winding per pole. The resistance of the shunt-field circuit is 39.65 ohms with the regulating rheostat cut out. A current of 9.3 amp. in the shunt field alone is the normal excitation, *i.e.*, for full load and unity power factor. With an output of 800 kw. at 600 volts, what is the least power factor at which the converter can be operated when overexcited? What per cent is the current of its full-load value? Neglect any change in this efficiency.

117.[1] A 3-phase, 25-cycle synchronous converter has a full-load capacity of 300 kw. at 600 volts. The armature has 96 slots with 6 inductors in series per slot. The field structure has 4 poles with 2340 turns in the shunt winding per pole. The resistance of this field circuit with all of the regulating rheostat

[1] In calculating the armature reaction, do not neglect the distribution of the winding, and assume that the constant usually given as 0 707 is 0.75. This makes an approximate correction for the effect of the ratio of pole arc to pole pitch.

cut out is 120.5 ohms. A current of 3.25 amp. in the shunt-field winding alone gives the normal excitation, *i.e.*, for full load at unity power factor. In order to maintain the terminal potential on the direct-current side at 600 volts when full load is delivered, it is necessary to overexcite the converter so that it takes a line current of 600 amp. at a power factor of 86 per cent. (*a*) Calculate the least number of series field turns that must be added in order that this excitation may be produced. What should be the current in the shunt-field winding? (*b*) Calculate the least number of series turns that must be added in order that this excitation may be produced if the shunt-field current is maintained constant at the value for which the power factor is unity at no load with a potential of 600 volts. What portion of the output current should flow through these series turns?

118. A 1200-volt, 1000-kw., 6-phase, compound, 60-cycle synchronous converter is operating at rated potential and unity power factor with an output of 800 kw. If the load increases to 1200 kw., how much must the shunt-field current be changed to maintain unity power factor? Must it be increased or decreased? Assume that the potential and frequency on the alternating-current side remain unchanged, and neglect the resistance and leakage reactance of the armature. The following data are given concerning the converter:

Number of poles	12	Armature resistance between direct-current brushes	0.0236 ohm
Number of armature slots	180	Shunt-field resistance	147 ohms
Number of series armature inductors per slot	12	Series-field resistance	0.0025 ohm
Number of shunt turns per pole	1628	Friction and windage loss	9.1 kw.
Number of series turns per pole	4		

119. A compound converter is delivering a constant output at a constant potential. When the shunt-field current is 11.2 amp., the power factor is unity. With the shunt rheostat all cut in, the shunt-field current is 9.2 amp., and the power factor is 0.90. With the shunt rheostat all cut out, the shunt-field current is 13 amp. What is the power factor at the time?

120. The following data are given concerning a synchronous converter: 1000 kw., output; 600-volts, direct current; 6 phases; 60 cycles; 12 poles; 180 armature slots; 6 inductors per slot; 864 shunt and 2 series turns per pole. A shunt-field current of

9.3 amp. is necessary to give 600 volts at no load. The resistance of the series-field turns is 0.0006095 ohm. What resistance should be shunted across the series field so that at full-load output and with a leading power factor of 0.95 on the alternating-current side, the terminal voltage will be maintained at 600 volts without changing the shunt-field current, *i.e.*, $I_f = 9.3$? Where it is necessary to use the efficiency, it may be assumed to be 0.97.

121. What is the necessary shunt-field excitation so that converter A, . . . E, . . . or I will operate at (*a*) unity power factor, (*b*) 0.92 power factor (lagging), (*c*) 0.92 power factor (leading) when it is delivering its rated output on the direct-current side?

122. At what power factor will converter A, . . . E, . . . or I operate when it is delivering its rated direct-current output if the shunt-field rheostat is cut out?

123. The alternating current supplied to a synchronous converter has its normal value when the converter delivers its rated direct-current output and operates at unity power factor. The efficiency may be assumed to be 0.96. When synchronous converter A, . . . E, . . . or I delivers 0.90 of its rated output at its rated direct-current potential, over what range is it possible to vary the shunt-field excitation without having the alternating-current input exceed its normal value?

124. What is the least leading power factor at which synchronous converter A, . . . E, . . . or I can be operated when it is delivering its rated direct current at a potential 0.10 greater than the rated value?

125. The potential of the circuit which supplies synchronous converter A, . . . E, . . . or I with power is maintained constant so that the converter delivers its direct-current output at the rated potential. The shunt field is adjusted so that the converter operates at unity power factor with no output. Without changing the shunt field, is it possible to adjust a shunt about the series field so that the converter will operate at a leading power factor of 0.95 when it delivers its rated output? If so, what is the resistance of the shunt? If not, what is the least number of series turns that must be added so that the desired result can be accomplished when the proper shunt is used about the entire series field? What will be the value of the shunt resistance in this case?

126. Synchronous converter A, . . . E, . . . or I is operated at the end of a feeder which has a resistance of 0.10[1] and a reactance of such value that, with a constant potential applied to the feeder, the potential at the converter is the same when the converter delivers 0.40 of its rated output while operating at 0.80 power factor (lagging) as when the converter delivers its rated output while operating at 0.95 power factor (leading). The direct-current potential of the converter has its rated value under these conditions. (*a*) Compute the per cent value of the reactance of the feeder. (*b*) What adjustments can be made with respect to the series field—by adding series turns or by means of a shunt—which will automatically adjust the power factor as specified while the shunt-field current is maintained constant?

127.[2] Calculate the efficiency of the synchronous converter A when it receives 300 kw. at a power factor of 0.90, (*a*) lagging, (*b*) leading, and with a line potential of 380 volts. Assume that the operating temperature is 70°C.

128.[2] Calculate the efficiency of the synchronous converter A when it delivers 300 kw. at 625 volts and the excitation is greater than normal and is adjusted so that the line current on the alternating-current side is 520 amp. Assume that the operating temperature is 70°C.

[1] The resistance drop per conductor when the converter delivers its rated output and operates at unity power factor is 0.10 of rated phase potential of the converter.

[2] In calculating the armature reaction do not neglect the distribution of the winding, and assume that the constant usually given as 0.707 is 0.75. This makes an approximate correction for the effect of the ratio of pole arc to pole pitch.

DATA ON SYNCHRONOUS CONVERTERS

	A	B	C
Kilowatt	300	1,000	1,000
Potential, direct current	600	600	600
Current, direct current	500	1,667	1,667
Phases	3	6	6
Frequency	25	25	60
Poles	4	8	12
Armature slots	96	168	180
Inductors per slot	6	6	6
Turns per pole:			
Shunt	2340	1,501	864
Series	9	2	2
Resistance at 25°C.:			
Armature between direct-current brushes	0.030	0.00688	0.00589
Shunt field[1] (alone)	120.5	76.6	39.65
Series field	0.00248	0.00042	0.0006095
Friction and windage, kilowatts	3.2	6.7	9.1

[1] The shunt field has a regulating rheostat in series with it, the loss in which should be included in calculating the efficiency.

DIRECT-CURRENT SATURATION CURVES AND CORE LOSSES

Ordinates	Abscissæ					
Direct-current potential	Shunt-field currents			Core losses		
	A	B	C	A	B	C
550	2.70	4.90	7.9	1.96	4.68	12.4
600	3.25	5.60	9.3	2.52	5.50	14.7
650	4.00	6.26	11.2	3.25	6.40	17.7
700	5.00	7.44	14.0	4.23	7.70	21.6

129.[1] Calculate the efficiency of the synchronous converter B when it delivers 1000 kw. at 650 volts and the shunt-field rheostat

[1] In calculating the armature reaction, do not neglect the distribution of the winding, and assume that the constant usually given as 0.707 is 0.75. This makes an approximate correction for the effect of the ratio of pole arc to pole pitch.

The shunt field has a regulating rheostat in series with it, the loss in which should be included in calculating the efficiency.

As a first approximation, it may be assumed that the efficiency is 95 per cent.

is cut out. Assume that the operating temperature is 70°C. What are the line current and power factor on the alternating-current side?

130.[1] Calculate the efficiency of the synchronous converter C when it delivers 1000 kw. at 650 volts and the excitation is adjusted so that the power factor is 0.95, (*a*) lagging, (*b*) leading. Assume that the operating temperature is 70°C.

131. What is the efficiency of synchronous converter A, . . . E, . . . or I when it is delivering its rated output and is operating at (*a*) unity power factor, (*b*) 0.95 power factor (lagging), (*c*) 0.95 power factor (leading), (*d*) 0.90 power factor (leading)? Assume that the operating temperature is 80°C.

132. Compute the efficiency of synchronous converter A, . . . E, . . . or I when it delivers its rated output and the shunt-field rheostat is cut out. Assume that the operating temperature is 80°C.

133. When synchronous converter A, . . . E, . . . or I is delivering its rated output, what change in the losses will be produced by reducing the power factor from unity to 0.95? Assume that the operating temperature is 80°C.

134. Synchronous converter A, . . . E, . . . or I is operating with a constant applied potential and a leading power factor of 0.95 while it is delivering its rated output. What change will be produced in the losses if the series turns are short circuited and the shunt-field current is unaltered?

[1] In calculating the armature reaction, do not neglect the distribution of the winding, and assume that the constant usually given as 0.707 is 0.75. This makes an approximate correction for the effect of the ratio of pole arc to pole pitch.

The shunt field has a regulating rheostat in series with it, the loss in which should be included in calculating the efficiency.

As a first approximation, it may be assumed that the efficiency is 95 per cent.

SYNCHRONOUS-CONVERTER DATA

Number	D	E	F	G	H	I
Kilowatt	1 000	1 500	3 000	3 000	3 900	4 000
Potential, direct current	660	250	600	575	300	600
Phases	6	6	6	6	6	6
Cycles	60	60	60	25	60	25
Poles	8	16	18	12	18	14
Armature slots	120	240	270	288	360	252
Conductors per slot	6	4	6	4	4	4
Turns per pole						
Shunt	1 050	305	680	738	210	535
Series	2	2	2[1]	2	none	¾
Resistance at 25°C						
Armature between direct-current brushes	0 0101[2]	0 00155	0 00196	0 00364	0 000477	0 00173
Shunt field, alone	59 85	6 08	34 0	32 0	3 24	23 1
Series field	0 000966	0 000156	0 000215	0 00045	none	0 000230
Commutating field			0 000369		0 00007	0 000190
Friction and windage, kilowatts	9 5	18 0	36 3	13 9	32 0	22 0

[1] Series field has two equal parallel paths
[2] At 75°C

SYNCHRONOUS-CONVERTER DATA

Saturation curves and ore losses

Ordinates potential, direct current	Abscissæ											
	Shunt-field currents						Core losses, kilowatts					
	D	E	F	G	H	I	D	E	F	G	H	I
500	5 0		9 52	9 0		11 9	5 7		18 2	10 5		16 3
550	6 1		11 5	10 6		13 8	7 3		22 9	13 1		19 7
600	7 5		14 2	12 5		15 9	9 5		29 3	16 4		23 1
650	9 3		18 3	15 2		18 1	12 4		37 7	20 8		26 8
700	11 8		24 1	19 3		21 3	16 0		48 5	26 7		31 0
200		13 3			15 7			6 2			9 75	
220		15 1			18 0			7 8			11 5	
250		19 0			21 6			11 0			14 8	
270		22 5			24 5			13 6			17 8	
280		24 6			26 3			15 2			19 6	
300		30 5			30 2			18 8			24 0	
320		38 2			36 9			23 0				

CHAPTER V

INDUCTION MOTOR

1. A 2-phase induction motor has a stator with 2 slots per pole per phase. There are 4 inductors in series per slot. The coil pitch is 4 slots. The effective value of the current in each phase of the stator winding is 7.07 amp., and the current in phase 2 lags the current in phase 1 by 90 electrical deg. Place the first slot in phase 1 at the extreme left of the paper, and draw the zero lines to allow for a maximum ordinate of 2 in. Use the following scales in these plots:

Abscissæ	pole pitch = 3 in.
Ordinates	40 ampere-turns = 1 in.

Plot the distribution of the m.m.f. across the air gap due to the stator currents (*a*) at the time that the current in phase 1 is a maximum, (*b*) at one-eighth of a period later than in (*a*), (*c*) at one-quarter of a period later than in (*a*).

2. A 2-phase induction motor has a stator with 4 slots per pole per phase. There are 4 inductors in series per slot. The coil pitch is 8 slots. The effective value of the current in each phase of the stator winding is 7.07 amp., and the current in phase 2 lags the current in phase 1 by 90 electrical deg. Place the first slot in phase 1 at the extreme left of the paper, and draw the zero lines to allow for a maximum ordinate of 3 in. Use the following scales in these plots:

Abscissæ	pole pitch = 3 in.
Ordinates	40 ampere-turns = 1 in.

Plot the distribution of the m.m.f. across the air gap due to the stator currents (*a*) at the time that the current in phase 1 is a maximum, (*b*) at one-eighth of a period later than in (*a*), (*c*) at one-quarter of a period later than in (*a*).

3. A 2-phase induction motor has a stator with 4 slots per pole per phase. There are 4 inductors in series per slot. The coil pitch is 6 slots. The effective value of the current in each phase of the stator winding is 7.07 amp., and the current in

phase 2 lags the current in phase 1 by 90 electrical deg. Place the first slot in phase 1 at the extreme left of the paper, and draw the zero lines to allow for a maximum ordinate of 3 in. Use the following scale in these plots:

Abscissæ........................	pole pitch = 3 in.
Ordinates........................	40 ampere-turns = 1 in.

Plot the distribution of the m.m.f. across the air gap due to the stator currents (*a*) at the time that the current in phase 1 is a maximum, (*b*) at one-eighth of a period later than in (*a*), (*c*) at one-quarter of a period later than in (*a*).

4. A 3-phase induction motor has a stator with 2 slots per pole per phase. There are 4 inductors in series per slot. The coil pitch is 6 slots. The effective value of the current in each phase of the stator winding is 7.07 amp., and the current in phase 2 lags the current in phase 1 by 120 electrical deg. and leads the current in phase 3 by the same amount. Place the first slot in phase 1 at the extreme left of the paper, and draw the zero lines to allow for a maximum ordinate of 2 in. Use the following scales in these plots:

Abscissæ........................	pole pitch = 3 in.
Ordinates........................	40 ampere-turns = 1 in.

Plot the distribution of the m.m.f. across the air gap due to the stator currents (*a*) at the time that the current in phase 1 is a maximum, (*b*) at one-eighth of a period later than in (*a*), (*c*) at one-quarter of a period later than in (*a*).

5. A 3-phase induction motor has a stator with 4 slots per pole per phase. There are 4 inductors in series per slot. The coil pitch is 12 slots. The effective value of the current in each phase of the stator winding is 7.07 amp., and the current in phase 2 lags the current in phase 1 by 120 electrical deg. and leads the current in phase 3 by the same amount. Place the first slot in phase 1 at the extreme left of the paper, and draw the zero lines to allow for a maximum ordinate of 4 in. Use the following scales in these plots:

Abscissæ........................	pole pitch = 3 in.
Ordinates........................	40 ampere-turns = 1 in.

Plot the distribution of the m.m.f. across the air gap due to the stator currents (*a*) at the time that the current in phase 1 is

a maximum, (*b*) at one-eighth of a period later than in (*a*), (*c*) at one-quarter of a period later than in (*a*).

6. A 3-phase induction motor has a stator with 4 slots per pole per phase. There are 4 inductors per slot, 2 of which are in one coil and 2 in another. The coil pitch is 10 slots. There are 2 coil sides in each slot. The effective value of the current in each phase of the stator winding is 7.07 amp., and the current in phase 2 lags the current in phase 1 by 120 electrical deg. and leads the current in phase 3 by the same amount. Place the first slot in phase 1 at the extreme left of the paper, and draw the zero lines to allow for a maximum ordinate of 4 in. Use the following scales in these plots:

Abscissæ........................	pole pitch = 3 in.
Ordinates........................	40 ampere-turns = 1 in.

Plot the distribution of the m.m.f. across the air gap due to the stator currents (*a*) at the time that the current in phase 1 is a maximum, (*b*) at one-eighth of a period later than in (*a*), (*c*) at one-quarter of a period later than in (*a*).

7. A 3-phase induction motor has a stator with 21 slots per pair of poles. Each coil has 2 turns, and there are two coil sides per slot. The coil pitch is 10 slots. The winding is arranged so that the successive phase groups consist alternately of 3 and 4 coils. The effective value of the current in each phase of the stator winding is 7.07 amp., and the current in phase 2 lags the current in phase 1 by 120 electrical deg. and leads the current in phase 3 by the same amount. Place the first slot in phase 1 at the extreme left of the paper, and draw the zero lines to allow for a maximum ordinate of 4 in. Use the following scales in these plots:

Abscissæ........................	pole pitch = 3 in.
Ordinates........................	40 ampere-turns = 1 in.

Plot the distribution of the m.m.f. across the air gap due to the stator currents (*a*) at the time that the current in phase 1 is a maximum, (*b*) at one-eighth of a period later than in (*a*), (*c*) at one-quarter of a period later than in (*a*).

8. A 3-phase induction motor has a stator with 21 slots per pair of poles. Each coil has 2 turns, and there are two coil sides per slot. The coil pitch is 8 slots. The winding is arranged so that the successive phase groups consist alternately of 3 and 4 coils.

The effective value of the current in each phase of the stator winding is 7.07 amp., and the current in phase 2 lags the current in phase 1 by 120 electrical deg. and leads the current in phase 3 by the same amount. Place the first slot in phase 1 at the extreme left of the paper, and draw the zero lines to allow for a maximum ordinate of 4 in. Use the following scales in these plots:

Abscissæ..........................	pole pitch = 3 in.
Ordinates..........................	40 ampere-turns = 1 in.

Plot the distribution of the m.m.f. across the air gap due to the stator currents (*a*) at the time that the current in phase 1 is a maximum, (*b*) at one-eighth of a period later than in (*a*), (*c*) at one-quarter of a period later than in (*a*).

9. Assume that the stator winding of a 3-phase induction motor is uniformly distributed. The coil pitch is unity, and the phase spread is one-third the polar pitch. The current in phase 2 lags the current in phase 1 by 120 deg. and leads the current in phase 3 by the same amount. Place the beginning of phase 1 at the extreme left of the paper, and draw the zero lines to allow for a maximum ordinate of 3 in. As ordinates, let 1 in. equal the maximum ampere-turns per pole per phase; and as abscissæ, let 3 in. equal the pole pitch. Plot the distribution of the m.m.f. across the air gap (*a*) at the time that the current in phase 1 is a maximum, (*b*) at one-eighth of a period later than in (*a*), (*c*) at one-quarter of a period later than in (*a*).

10. Assume that the stator winding of a 3-phase induction motor is uniformly distributed. The coil pitch is unity, and the phase spread is two-thirds the polar pitch. The current in phase 2 lags the current in phase 1 by 120 deg. and leads the current in phase 3 by the same amount. Place the beginning of phase 1 at the extreme left of the paper, and draw the zero lines to allow for a maximum ordinate of 3 in. As ordinates, let 1 in. equal the maximum ampere-turns per pole per phase; and as abscissæ, let 3 in. equal the pole pitch. Plot the distribution of the m.m.f. across the air gap (*a*) at the time that the current in phase 1 is a maximum, (*b*) at one-eighth of a period later than in (*a*), (*c*) at one-quarter of a period later than in (*a*).

11. A 4-pole, 3-phase, Y-connected induction motor has 6 slots per pole with 20 series inductors per slot. The coils of each phase are connected in series and have a pitch of 5 slots. The mean

radius of the air gap is 20 cm., and the length of the armature core parallel to the shaft is 15 cm. The length of the air gap is 1 mm. The effective value of the magnetizing current per phase is 14.1 amp. Assume that the permeability of the stator and rotor iron is infinite, and neglect the effect of the slots. Plot the curve of flux density in the air gap, and determine the flux per pole at the moment when the current in 1 phase is (*a*) passing through its maximum value, (*b*) passing through 0.866 of its maximum value and decreasing, (*c*) passing through 0.50 of its maximum value and decreasing, (*d*) passing through zero.

12. Determine the maximum flux density in the air gap of motor Q, T, . . or *Z* when it is operating at no load with rated potential applied at the terminals. Neglect the resistance and leakage reactance of the stator.

13. Compute the e m.f. generated in each rotor bar of motor Q, R, T, U, or V when rated potential is applied to the stator terminals, and the slip is 2 per cent. In this problem, neglect the resistance and leakage reactance of the stator winding.

14. Compute the e.m.f. generated in each phase of the rotor of motor S, W, X, Y, or Z when rated potential is applied to the stator terminals, and the slip is 2 per cent. In this problem, neglect the resistance and leakage reactance of the stator winding.

15. (*a*) With rated potential applied at two of the three terminals of the stator of motor S, W, X, Y, or Z, what will be the greatest e.m.f. generated in each phase of the open-circuited rotor winding at standstill? (*b*) What will be the maximum flux densities in the air gap? (*c*) What per cent of the normal no-load magnetizing current will flow in the stator winding? In this problem, neglect the resistance and leakage reactance of the stator winding.

16. (*a*) If two of the terminals of motor S, W, X, Y, or Z are connected, and rated line potential is applied between them and the third terminal, what is the greatest value of the e.m.f. generated in one phase of the open-circuited rotor winding at standstill? (*b*) What is the ratio of the maximum flux density in the air gap to the maximum density during normal operation? (*c*) What per cent of normal no-load magnetizing current will be supplied to the stator? In this problem, neglect the resistance and leakage reactance of the stator winding.

17. Both the stator and rotor of an induction motor have symmetrical 2-phase windings. With the rotor windings open

circuited and with a potential of V_1 applied to one phase of the stator, the stator current and power are, respectively, I_1 and P_1. The greatest potential at the terminals of one of the rotor phases is E_2, and as the rotor is turned on its shaft this potential varies sinusoidally with the rotor position. With the stator windings open circuited and with a potential of V_2 applied to one phase of the rotor, the rotor current and power are, respectively, I_2 and P_2. The greatest potential at the terminals of one of the stator phases is E_1, and as the rotor is turned on its shaft this potential varies sinusoidally with the rotor position. (*a*) With the rotor windings open circuited and stationary, and with balanced potentials of V_1 per phase applied to the stator windings, determine the magnitudes and relative phase of the e.m.fs. generated in the rotor windings. (*b*) With the rotor windings short circuited and stationary, and with balanced potentials of V_1 per phase applied to the stator windings, determine the magnitudes and relative phase of the currents in the rotor windings.

18. Both the stator and rotor of an induction motor have symmetrical 2-phase windings. With the rotor windings open circuited, and with a potential of V_1 applied to one phase of the stator, the stator current and power are, respectively, I_1 and P_1. The greatest potential at the terminals of one of the rotor phases is E_2, and as the rotor is turned on its shaft this potential varies sinusoidally with the rotor position. With the stator windings open circuited, and with a potential of V_2 applied to one phase of the rotor, the rotor current and power are, respectively, I_2 and P_2. The greatest potential at the terminals of one of the stator phases is E_1, and as the rotor is turned on its shaft this potential varies sinusoidally with the rotor position. (*a*) With the rotor stationary and with only one of its phases short circuited, what will be the greatest e.m.f. generated in one of the phases of the stator when a potential of V_1 is applied to the other phase of the stator? What will be the greatest value of the stator current? (*b*) With the rotor stationary and with both of its phases short circuited, what will be the greatest e.m.f. generated in one of the phases of the stator when a potential of V_1 is applied to the other phase of the stator? What will be the greatest value of the stator current?

19. The stator of a polyphase induction motor is series wound for N_1 poles, and the rotor is series wound for a different number

of poles N_2. Determine the e.m.f. per phase generated in the rotor when balanced potentials are applied to the stator. The complete winding data are available.

20. At no load, a 25 hp. induction motor takes 865 watts at 0.18 power factor from a 250-volt, 3-phase circuit. The effective resistance of the stator winding is 0.3 ohm between terminals. Neglect the leakage reactance. What would have been the no-load power and power factor if the motor had been designed with an air gap which would have made the reluctance of the magnetic circuit 25 per cent greater?

21.[1] A 200-hp. induction motor is designed to operate from a 3-phase, 980-volt, 20-cycle circuit. Under this condition, the no-load power and power factor are 6.62 kw. and 0.086. The friction and windage loss is 4.0 kw. The stator winding is Δ-connected and has an effective resistance of 0.387 ohm per phase. What will be the no-load power and power factor if this motor is operated from a 3-phase, 1100-volt, 25-cycle circuit? Neglect the leakage reactance, and assume that the core losses vary as $B^{1.7}f^{1.3}$. $(F + W)$ varies as (speed)^2.

22.[1] At no load, a 570-hp., 1900-volt, 3-phase induction motor takes 15.1 kw. at 0.081 power factor. The friction and windage loss is 12.0 kw. The effective resistance of the stator winding is 0.757 ohm per phase. The windings are connected in Δ. There are 8 inductors in series per slot. If the motor is rewound with the same-size wire but with 6 inductors in series per slot, what no-load current and power will it take from the same circuit? Neglect the leakage reactance and assume that the core losses vary as $B^{1.7}f^{1.3}$.

23.[1] At no load, a 335-hp., 3-phase induction motor takes a line current of 15.5 amp. and absorbs 10.1 kw. from a 2000-volt, 50-cycle circuit. The effective resistance and the leakage reactance of the stator winding are, respectively, 0.248 and 0.76 ohm per phase. The windings are connected in Y. The friction and windage loss is 2.5 kw. What current and power will this motor take at no load from a 2200-volt, 60-cycle circuit? Assume that the core losses vary as $B^{1.7}f^{1.3}$ and that the generated e.m.f. due to the air gap flux is equal to the applied potential less the magnetizing current multiplied by the leakage reactance.

24.[1] If the potentials applied to motor Q, . . . T, . . . or Z are (*a*) increased 10 per cent above normal, (*b*) decreased 10 per

[1] For saturation curve, see p. 223.

cent below normal, what will be the no-load current and power? The frequency is maintained normal.

25.[1] If the frequency of the potentials applied to motor Q, . . . T, . . . or Z are (*a*) increased 10 per cent above normal, (*b*) decreased 10 per cent below normal, what will be the no-load current and power? The magnitude of the potentials is maintained normal.

26.[1] At no load, a 150 hp., 3-phase induction motor takes a line current of 46 amp. and absorbs 5.65 kw. from a 500-volt, 38-cycle circuit. The friction and windage loss is 3.1 kw. The stator has 12 slots per pole, and the winding pitch is 12 slots. If this motor is rewound with the same number of turns, using a pitch of 10 slots, what current and power will it take at no load from the same circuit? Neglect the resistance and the leakage reactance, and assume that the core losses vary as $B^{1.7}f^{1.3}$.

27.[1] The stator of a 150-hp., 3-phase, 500-volt induction motor has 108 slots, and in each of the following cases it is wound for 6 poles with 4 inductors per slot: With a winding pitch of 18 slots, the core losses are 2.9 kw., and the magnetizing current is 45 amp. If a winding pitch of 14 slots is used, what will be the core losses and the magnetizing current at the same potential and frequency? Assume that the core losses vary as $B^{1.7}$.

28.[1] Compute the no-load current and power with rated applied potential if the winding pitch is changed to (*a*) 10 slots in motor S, (*b*) 7 slots in motor W, (*c*) 15 slots in motor X, (*d*) 9 slots in motor Y, (*e*) 14 slots in motor Z.

29.[1] Both the stators and rotors of two 150-hp., 3-phase induction motors are of the same design except that one is wound for 6 poles and the other for 8 poles. Each stator has the same number of slots with the same number of inductors per slot. The 6-pole motor takes 5.7 kw. from a 500-volt, 38-cycle circuit at no load, and the line current is 46 amp. The friction and windage loss is 2.9 kw. The effective resistance of the stator winding is 0.082 ohm per phase. The effective resistance of the stator winding of the 8-pole motor is 11 per cent less than this. The windings are connected in Y. What current and power will the 8-pole motor take at no load from the same circuit? Assume that the friction and windage loss varies as the square of the speed, and neglect the leakage reactance. Where approximations are made, state what they are.

[1] **For saturation curve, see p. 223.**

30.[1] The stator of a 25-hp., 3-phase, 250-volt induction motor has 72 slots, and in each of the following cases it is wound with 8 inductors per slot: If this motor is wound for 8 poles, with a winding pitch of 8 slots, the core losses are 590 watts, the friction and windage loss is 220 watts, and the magnetizing current is 11 amp. What current and power will this motor take from the same circuit at no load if it is wound for 6 poles with a winding pitch of 10 slots? Neglect the resistance and leakage reactance, and assume that the friction and windage loss varies as the speed and that the core losses vary as $B^{1.7}f^{1.3}$.

31. With normal frequency and applied potential, what will be the new values of the no-load current and power if the stator coils (*a*) of motor R are reconnected to give 8 poles, (*b*) of Motor U are reconnected to give 6 poles, (*c*) of motor V are reconnected to give 16 poles, (*d*) of Motor Y are reconnected to give 8 poles?

32. Three equal resistances of 0.55 ohm each are connected in Y to the rotor slip rings of the motor described in problem 88 (p. 208). Compute the torque, the line current, and the power factor at the instant of starting with normal line potential applied to the stator. If the rotor is short circuited, what applied line potential is necessary in order that the starting torque will be unchanged. What is the power factor for this latter condition? Assume that the stator and rotor core losses are equal at the instant of starting and that they vary as the 1.7 power of the flux density. The full-load line current and slip of this motor are 169 amp. and 0.0257, respectively. The saturation curve is given on page 223.

33. Compute the current, power factor, output, efficiency, torque, and slip at the instant of breakdown when motor I (p. 211) is operated at its normal line potential. How much resistance must be inserted between each pair of rotor slip rings in order that this motor will develop its maximum torque at starting? Compare the breakdown torque with the full-load torque. In this comparison, assume that the full-load slip is 0.018. Assume that the temperature is 25°C., that the friction and windage loss is 3100 watts, and that the ratio of effective to ohmic resistance is the same for stator and rotor.

34. A 3-phase, 2200-volt, 25-cycle, 12-pole induction motor has a full-load capacity of 1000 hp. The stator and rotor are Y-connected and have ohmic resistances of 0.065 and 0.0386 ohm per

[1] For saturation curve, see p. 223.

phase, respectively. Assume that the ratios of effective to ohmic resistances are the same for the stator and rotor and that the reactances are equal when both are referred to the stator. The ratio of transformation is 2200:1500. At no load, the motor takes 15.2 kw. with a line current of 75.1 amp. at rated potential. With the rotor blocked and a line potential of 400 volts, the current and power are 346.5 amp. and 68 kw., respectively. Compute the breakdown torque and ratio of breakdown torque to full-load torque; also, compute how much resistance must be placed between each pair of slip rings (Δ connection) to give maximum torque at starting. The friction and windage loss is 3.1 kw.

35.[1] The stator of a 25-hp., 3-phase, 50-cycle induction motor is wound for 250 volts. With an applied potential of 110 volts, the starting current is 61 amp. at 0.336 power factor. The effective resistance and leakage reactance of the stator windings are, respectively, 0.159 and 0.46 ohm per phase. The stator has 72 slots, with 9 inductors per slot, and the rotor has 120 slots, with 2 inductors per slot. Both the stator and rotor windings are connected in Y. The ohmic resistance of the rotor winding is 0.015 ohm per phase. What is the leakage inductance of the rotor winding per phase? What is the ratio of effective to ohmic resistance for the rotor winding at 50 cycles? If the stator is rewound for 500 volts by using twice as many turns of wire of one-half the size, what potential should be applied to have a starting current of 30 amp.?

36.[1] The full-load line current taken by a 200-hp., 3-phase, 980-volt induction motor is 101 amp. The stator has 216 slots, with 5 inductors per slot, and the ohmic resistance of the winding is 0.246 ohm per phase. The rotor has 288 slots, with 1 inductor per slot, and the ohmic resistance of the winding is 0.010 ohm per phase. Both the stator and rotor windings are connected in Δ. The leakage inductances of the stator and rotor windings are, respectively, 3.9 mil-henrys and 0.19 mil-henry per phase. At the rated frequency of 20 cycles, the ratios of effective to ohmic resistance are, respectively, 1.6 and 1.9 for the stator and rotor. (*a*) What potential should be impressed on this motor in order that the starting current will be twice the full-load current? (*b*) If the stator winding is reconnected in Y, what potential should be impressed on the motor in order that the starting current will be twice the full-load current? In this case, the rated potential becomes 1700 volts.

[1] **Assume that the ratio of transformation equals the ratio of turns.**

37. At full load, the stator and rotor copper losses of a 500-hp., 3-phase, 2000-volt induction motor are, respectively, 4.14 and 1.82 per cent. The core loss is 2470 watts, and the friction and windage loss is 11.0 kw. The magnetizing component of the line current is 23 amp. At the rated frequency of 60 cycles, the ratio of effective resistance to ohmic resistance is 1.55 for the stator winding and 1.85 for the rotor winding. At the rated frequency, the leakage reactances of the windings are 3.2 times their effective resistances. What line potential should be impressed on this motor when starting to give a line current of 200 amp.?

38.[1] The ohmic resistances of the stator and rotor windings of an induction motor are, respectively, 0.04 and 0.01 ohm. At normal frequency, the ratios of effective resistance to ohmic resistance are, respectively, 1.5 and 1.8 for the stator and rotor windings, and the leakage reactances are 3.1 times their effective resistances. The stator winding has 108 inductors per phase, and the rotor winding has 54 inductors per phase. Assume that the core loss due to leakage flux and the increase in the resistance due to a non-uniform distribution of current over the cross-section of the inductors both vary directly as the frequency. If the potential impressed on this induction motor when starting is increased (*a*) 30 per cent, how much is the starting current increased? How much is the starting torque increased? (*b*) If the frequency of the applied potential alone is increased 10 per cent, how much is the starting current decreased? How much is the starting torque decreased?

39.[1] The effective resistances of the stator and rotor windings of a 3-phase induction motor are 0.071 and 0.0218 ohm per phase, and the leakage reactances at normal frequency are 0.22 and 0.066 ohm per phase. The stator has 108 slots, with 5 inductors per slot, and the rotor has 126 slots, with 2 inductors per slot. Both of the windings are connected in Y. At starting, with full applied potential, the current is 3.6 times the full-load value, and the torque is 0.62 of the full-load torque. What will be the starting current and the starting torque with full applied potential if resistances of 0.2 ohm are inserted in each phase of the rotor winding?

40. (*a*) What internal starting torque in pound-feet will induction motor H (p. 211) develop when started with its rotor

[1] Assume that the ratio of transformation equals the ratio of turns.

short circuited and with 750 volts at 25 cycles impressed on its stator? (*b*) What three, equal, non-inductive resistances must be connected between each pair of rotor slip rings in order that the internal starting torque of the motor with rated potential and frequency impressed on the stator will be the same as in part (*a*)? Assume that the temperature of the windings is 25°C., that the ratio of the effective resistances at 25 cycles is equal to the ratio of the ohmic resistances, that the ratio of the reactances at 25 cycles is equal to the ratio of the ohmic resistances, and that the rotor and stator windings are both Y-connected.

41. The full-load line current taken by a 200 hp., 3-phase, 980-volt induction motor is 100 amp. The stator has 216 slots, with 5 inductors in each, and the ohmic resistance of the winding is 0.246 ohm per phase. The rotor has 288 slots, with 1 inductor per slot, and the ohmic resistance of the winding is 0.010 ohm per phase. Both the stator and rotor windings are connected in Δ. The leakage inductances of the stator and rotor windings are respectively 3.9 mil-henrys and 0.19 mil-henry per phase. At the rated frequency of 20 cycles, the ratios of effective to ohmic resistance are, respectively, 1.6 and 1.9 for the stator and rotor. The motor has 24 poles. The winding pitches are unity. (*a*) If the exciting current is neglected, what potential at 20 cycles should be impressed on this motor, when its rotor windings are short circuited, in order that the starting current shall be twice the rated full-load current? (*b*) With twice the rated full-load current, what will be the internal starting torque in pound-feet? (*c*) Assuming that the air-gap flux is sinusoidally distributed, what is the air-gap flux per pole?

42. A 3-phase, 250-volt, 25-hp., squirrel-cage induction motor develops its full load at a slip of 5 per cent when operating with rated potential applied to the stator. The motor is connected to a constant-potential source of 300 volts through a line having a resistance of 0.090 ohm per wire and a reactance of 0.082 ohm per wire. The ohmic resistance of the stator is 0.20 ohm between terminals. A blocked test by the manufacturer gives the following data:

Terminal potential	173 volts
Line current	100 amp.
Total power	7,500 watts

The motor is started by connecting it directly to the line. Compute the starting torque in terms of rated full-load torque. State the principal approximations involved in the solution.

43. At standstill, with 2200 volts impressed on the stator terminals of a 3-phase induction motor, the potential across the open rotor slip rings is 610. With the rotor blocked and the slip rings short circuited, the line potential, line current, and power supplied to the stator are 750 volts, 288 amp., and 116 kw. What resistances should be connected (*a*) in star (*b*) in Δ to the rotor slip rings, so that, with 2200 volts applied to the stator, the rotor current will be unchanged? What is the ratio of the torques developed in the two cases?

44. A 570-hp., 3-phase induction motor is arranged so that it may be connected to the line through a compensator at starting. The motor is wound for 36 poles and a line potential of 1900 volts at 22.5 cycles. When the compensator reduces the line potential to 600 volts, the line current is 200 amp., and the power is 58.8 kw. at the instant of starting. The stator and rotor ohmic resistances are equal when reduced to the same side, and the effective resistances are 1.5 times as great as the ohmic. Neglect the no-load current. From the above data, it can be shown that full load occurs at a slip of 0.0215. (*a*) What is the starting torque with 600 volts impressed on the motor? (*b*) What is the pull-out torque, *i.e.*, the maximum torque, with 1900 volts impressed on the stator? (*c*) At what slip does breakdown occur? (*d*) If the motor is to be started by connecting it directly to the 1900-volt line, what resistance should be connected in series with each rotor phase in order that the starting torque will be equal to the full-load torque? Assume that the rotor windings are Y-connected and that the ratio of transformation is 6:1.

45. It is to be decided whether to start an induction motor by means of a compensator, which reduces the potential applied to the stator terminals, or by inserting balanced resistances in the rotor circuit. In each case, the current drawn from the supply circuit must be the full-load current taken by the motor under normal operating conditions, *i.e.*, with full potential applied and the slip rings short circuited. With 25 per cent of rated potential, the motor takes full-load current at 20 per cent power factor, when the rotor is blocked and short circuited. Assume that the stator and rotor resistances at this time are equal. Compare the starting torques for the two methods of starting.

46. The following data are given concerning a 10-hp. 440-volt, 25-cycle, 3-phase, 6-pole induction motor: ratio of primary effective turns to secondary effective turns, 3.47; primary and

secondary windings, Y-connected; ohmic resistance of primary winding per phase, 0.71 ohm; ohmic resistance of secondary winding per phase, 0.084 ohm; ratio of effective resistance to ohmic resistance for both windings at 25 cycles, 1.25; primary leakage reactance per phase at 25 cycles, 1.76 ohms; secondary leakage reactance per phase at 25 cycles, 0.151 ohm; no-load current at rated frequency and potential, 9.6 amp.; no-load core loss, 480 watts; no-load friction and windage loss, 156 watts. If the exciting current is neglected, (*a*) what internal starting torque in pound-feet will be developed when the motor is started with its rotor short circuited and with 440 volts at 25 cycles impressed on its stator? (*b*) What will be the power factor of the motor when started under these conditions? (*c*) What current will be taken from the line when the motor is thus started?

47. Estimate as accurately as possible the starting torque when 0.5 rated potential is applied to motor Q, . . . T, . . . or Z. State the assumptions that are necessary.

48. Motor Q, . . . T, . or Z is to be started through a compensator. What should be its ratio of transformation so that the current taken from the line at the instant of starting will be the full-load current of the motor? The blocked data are taken with full-load current.

49. Motor Q, . . T, . . . or Z is started through a 2:1 compensator. What is the effect on the starting current, power factor, and torque of (*a*) a 10 per cent reduction in the line potential, (*b*) a 10 per cent increase in the line potential?

50. Motor Q, . . . T, . . . or Z is started through a 2:1 compensator. What is the effect on the starting current, power factor, and torque of (*a*) a 10 per cent reduction in the frequency of the applied potential, (*b*) a 10 per cent increase in the frequency of the applied potential? The magnitude of the line potential is normal.

51. Estimate as accurately as possible the ratio of the alternating to the direct-current resistance of the rotor of motor S, W, X, Y, or Z.

52. If the stator coils of motor Q, . . . V, X . . . or Z are reconnected to give a symmetrical 2-phase winding having the same number of poles, (*a*) what 2-phase line potential should be applied to produce normal air-gap flux density at no load? (*b*) With balanced 2-phase line potentials equal to 0.50 of the normal

3-phase line potential applied to the reconnected stator, what will be the starting current, power factor, and torque? The rotor winding is unchanged.

53. With normal frequency, what potential should be applied (*a*) to motor R if reconnected to give 8 poles, (*b*) to motor U if reconnected to give 6 poles, (*c*) to motor V if reconnected to give 16 poles, (*d*) to motor Y if reconnected to give 8 poles, in order that the coil current shall have its normal value at no load? The stator coils only are reconnected without any other change. Assume that both the resistance and reactance per phase vary directly with the number of coils per phase.

54. With full-load current, the slip and brake torque of a 500-hp., 3-phase, 60-cycle induction motor are 1.82 per cent and 16,300 lb.-ft. The ohmic resistance and leakage inductance of the rotor winding are 0.24 ohm and 3.1 mil-henrys per phase. What will be the slip, the brake torque, and the output when the current has its full-load value if resistances of 2 ohms are inserted in each phase of the rotor winding? Estimate the copper loss in each of these additional resistance units.

55. The resistance and leakage inductance of the rotor windings of a 3-phase, 38-cycle induction motor are 0.013 ohm and 0.27 mil-henry per phase. The full-load torque and slip are 2,190 lb.-ft. and 2.6 per cent. (*a*) To what per cent of its normal full-load value should the air-gap flux be reduced so that the motor will deliver its full-load torque at one-half the full-load speed? (*b*) What resistance should be inserted in each phase of the rotor so that the motor will deliver its full-load torque at one-half the full-load speed? Assume that the air-gap flux has its normal value. (*c*) Compare the rotor currents in (*a*) and (*b*).

56. The full-load distribution of losses in a 10-hp., 220-volt, 3-phase induction motor is:

	Per Cent
Stator copper loss	3.9
Rotor copper loss	4.8
Core loss	3.1
Friction and windage loss	4.0

What are the slip and efficiency at (*a*) full load, (*b*) one-half of full load?

57.[1] A 570-hp. induction motor is designed to receive power from a 3-phase, 1900-volt, 22.5-cycle circuit. The ohmic resistances of the stator and rotor windings are 0.488 and 0.0138 ohm per phase, and at rated frequency the effective resistances are 1.3 and 1.5 times as great. The leakage reactances at the rated frequency are three times the effective resistances. The stator has 864 inductors per phase, and the rotor 144 inductors per phase. The motor is wound for 36 poles, and both of the windings are connected in Δ. The friction and windage loss is 12 kw.

What is the slip at full load if the generated e.m.f. in the stator winding due to the air-gap flux is 93 per cent of the impressed potential? What is the starting torque with full potential impressed on the stator windings?

58.[1] At full load, the slip of a 335-hp., 2000-volt, 50-cycle, 6-pole induction motor is 1.8 per cent. The ohmic resistances of the stator and rotor windings are 0.165 and 0.0127 ohm per phase, and the leakage inductances are 2.4 mil-henrys and 0.22 mil-henry per phase. Both of the windings are connected in Y. The stator has 72 slots, with 10 inductors per slot, and the rotor has 90 slots, with 2 inductors per slot. The ratios of effective resistance to ohmic resistance at 50 cycles are 1.45 and 1.75 for the stator and rotor windings. At full load, the e.m.f. generated in the stator winding by the mutual flux is 93 per cent of the impressed potential. To what per cent of its full-load value should the air-gap flux be reduced so that the starting current will be 175 amp.? What is the starting torque for this condition? What are the full-load torque and rotor current?

59. In problem 58, what resistance should be inserted in each phase of the rotor winding so that when starting with normal line potential the rotor current will be twice its full-load value? What is the starting torque for this condition? What is the running torque with full-load current?

60. In problem 58, what reactance should be inserted in each phase of the rotor winding so that when starting with normal line potential the rotor current will be twice its full-load value? What is the starting torque for this condition? What is the running torque with full-load current?

61.[1] At the instant of starting on a reduced potential of 500 volts, a 500-hp., 3-phase, 60-cycle induction motor takes a

[1] Assume that the ratio of transformation equals the ratio of turns.

line current of 152 amp. at 0.31 power factor. The motor is wound for 44 poles. The ohmic resistance of the rotor winding is 0.0306 ohm measured between terminals before the winding is short circuited and the effective resistance is 1.7 times as great at the rated frequency. The stator winding has 704 inductors per phase, and the rotor winding has 220 inductors per phase. The friction and windage loss is 11 kw. What is the starting torque? With a line potential of 2000 volts, what brake torque would be delivered when the slip is 1.8 per cent? Assume that the impedance drop in the stator is 3.5 per cent of the applied potential at no load.

62. A 570-hp., 3-phase induction motor is arranged so that it may be connected to the line through a compensator at starting. The motor is wound for 36 poles and a line potential of 1900 volts at 22.5 cycles. When the compensator reduces the line potential to 600 volts, the line current is 200 amp., and the power is 58.8 kw. at the instant of starting. The stator and rotor ohmic resistances are equal when reduced to the same side, and the effective resistances are 1.5 times as great as the ohmic. The friction and windage loss at full load is 12 kw. The no-load line current is 56.6 amp. What is the slip when the motor delivers its rated load? What is the starting torque with 600 volts impressed on the motor?

63. At full load, the slip of a 500-hp., 3-phase induction motor is 1.80 per cent. The motor is wound for 12 poles and an applied potential of 2200 volts at 25 cycles. When the rotor winding is not short circuited, the hot resistance—referred to the stator—measured between terminals is 0.431 ohm, and the effective resistance is 1.65 times as much. What is the starting torque when the applied potential is adjusted so that the rotor current is twice its full-load value?

64. At full load, the slip of a 1000-hp., 3-phase induction motor is 1.72 per cent. The motor is wound for 12 poles and a line potential of 2200 volts at 25 cycles. When the rotor winding is not short circuited, the hot resistance measured between terminals is 0.0895 ohm, and the effective resistance is 1.6 times as great. The ratio of transformation from stator to rotor is 2200 to 1500. The effective resistance and leakage reactance of the stator winding between terminals are 0.195 and 0.59 ohm. The leakage reactance of the rotor between terminals is 0.29 ohms at 25 cycles. What potential should be impressed

on this motor so that the starting torque will be the same as the full-load torque? What is the starting current for this condition, and how does it compare with the full-load current?

65. In problem 64, what resistance should be inserted in each phase of the rotor winding in order that the starting torque for the rated potential will be equal to the full-load torque? What is the starting current for this condition, and how does it compare with the full-load current?

66. The full-load current and slip of a 1000-hp. 2000-volt, 25-cycle, 3-phase induction motor are 220 amp. and 0.019. At 25 cycles, the resistances of the stator and rotor windings are, respectively, 0.085 and 0.049 ohm per phase. The equivalent leakage reactance measured with the rotor blocked is 0.65 ohm per phase. The motor is wound for 12 poles, the windings are connected in Y, and the ratio of transformation is 2200:1500 volts. (*a*) What are the starting current and torque in per cent of full-load values with normal line potential impressed on the motor? (*b*) What resistance should be connected across the secondary slip rings so that the motor will develop full-load torque when starting with normal line potential?

67. At full load, the slip of a 1000-hp., 2200-volt, 25-cycle, 3-phase induction motor is 0.019. The resistance of the stator and rotor windings referred to the stator are, respectively, 0.083 and 0.105 ohm per phase at 25 cycles. The equivalent leakage reactance as measured on short circuit is 0.64 ohm per phase. The motor is wound for 12 poles, and the windings are connected in Y. The full-load current is 220 amp. The motor is started on reduced potential through a compensator. This compensator is designed so that at the first point the current taken from the 2200-volt circuit at the instant of starting is full-load current, *viz.*, 220 amp. Neglect the no-load current. What is (*a*) the ratio of transformation at the first point on the compensator, (*b*) the starting torque in per cent of full-load torque, (*c*) the breakdown torque in per cent of full-load torque when running with normal applied potential?

68. An 8-pole, 60-cycle, 3-phase, Y-connected (both rotor and stator), 2200-volt induction motor breaks down, when operated at rated potential and frequency, at 200 per cent full-load torque and at a slip of 16 per cent. The rotor ohmic resistance of this motor is 0.077 ohm per phase, and the ratio of effective resistance to the ohmic resistance at 60 cycles is 1.8. (*a*) What is the

minimum speed at which the motor can be operated, when developing full-load torque, by reducing the impressed potential? If the drop in the stator winding due to the exciting current is neglected, how much would the impressed potential have to be reduced? (*b*) How much resistance must be added between each pair of rotor slip rings in order that the motor shall develop 200 per cent full-load torque at starting with rated potential and frequency impressed on the stator? (*c*) If the number of turns in the rotor winding is doubled and the cross-section of the wire is halved, what will be the breakdown torque of the motor in per cent of its breakdown torque before the number of turns were changed? At what slip will this torque occur? The motor is assumed to operate at rated frequency and potential. (*d*) If the number of turns in the stator winding is doubled and the cross-section of the wire is halved, what will be the rating of the motor when operated at 4400 volts and 60 cycles? How will the full-load power factor, efficiency, torque, and slip at the new rating compare with the full-load power factor, efficiency, torque, and slip of the motor before its windings were changed?

69. The ohmic resistances of the stator and rotor windings of a 500-hp., 3-phase induction motor are 0.24 and 0.0153 ohm per phase, and the effective resistances at the rated frequency are, respectively, 1.5 and 1.6 times as great. The leakage reactances at the rated frequency are, respectively, 1.1 ohms and 0.075 ohm per phase. The motor is wound for 44 poles and an applied potential of 2000 volts at 60 cycles. The stator has 2112 inductors, and the rator 660 inductors. Both windings are connected in Y. At full load, the impedance drop in the stator winding due to the no-load current is 4 per cent of the applied potential. What resistances should be inserted in each phase of the rotor in order that the starting torque with normal applied potential may have its maximum value? What is this torque? What is the starting current for this condition, and how does it compare with the full-load current?

70. The ohmic resistances of the stator and rotor windings of a 150-hp., 3-phase railway induction motor are 0.054 and 0.014 ohm per phase, and the effective resistances at the rated frequency are, respectively, 1.45 and 1.65 times as great. The leakage reactances at the rated frequency are, respectively, 0.24 and 0.071 ohm per phase. The motor is wound for 6 poles and

a line potential of 500 volts at 38 cycles. The ratio of transformation from stator to rotor winding is 15:7, and both windings are connected in Y. With normal applied potential, the measured slip for a brake torque of 1470 lb.-ft. is 2.26 per cent. What resistances should be inserted in each phase of the rotor winding so that the starting torque with normal applied potential will have its maximum value? What is this torque?

INDUCTION-MOTOR DATA

	A	B	C	D	E
Horsepower	25	120	200	335	570
Line potential	250	500	980	2,000	1,900
Type of winding	Y	Y	Δ	Y	Δ
Frequency	50	38	20	50	22.5
Poles	8	6	24	6	36
Ohmic resistance per phase					
Stator	0.096	0.04	0.246	0.165	0.488
Rotor		0.01		0.0127	0.0138
Ratio of transformation		2:1		4:1	6:1
Magnetizing current, line	11		39		
Core loss	590		1,120		
Friction and windage loss	220		4,000		
No load: Line potential		500		2,000	1,900
No load: Line current		34.5		15.3	57.6
No load: Power		4,400		10,100	17,200
Blocked: Line potential	100	500	220	440	600
Blocked: Line current	57	800	173	170	200
Blocked: Power	3,100	220,000	20,400	40,500	65,000

71. A 1000-hp., 3-phase, 2200-volt, 25-cycle, 12-pole induction motor has the following constants:

$$r_1 \text{ ohmic} = 0.065 \text{ ohm per phase}$$
$$r_2 \text{ ohmic} = 0.039 \text{ ohm per phase}$$
$$x_1 = 0.313 \text{ ohm at 25 cycles}$$
$$x_2 = 0.147 \text{ ohm at 25 cycles}$$

Both stator and rotor windings are Y-connected and have a ratio of transformation of 22:15. The ratio of the effective to the ohmic resistances of the stator and of the rotor are each 1.4 at 25 cycles. At 30 cycles, they are each 1.5. (*a*) If this motor is operated at 30 cycles, what potential must be impressed on the stator in order that the flux density shall be the same as when operating at 25 cycles with 2200 volts impressed? The stator impedance drop may be neglected in finding this potential.

(*b*) If the motor is operated at the potential found under (*a*) and at 30 cycles, what will be its breakdown torque in per cent of its breakdown torque when operating at 2200 volts and 25 cycles? Neglect the drop due to the exciting current. (*c*) What will be the ratio of the secondary currents at breakdown in the two cases, *i.e.*, with the potential found under (*a*) at 30 cycles, and with 2200 volts at 25 cycles?

72. A certain load, which requires a starting torque of 80 lb.-ft., a full-load torque of 300 lb.-ft., and a maximum torque of 450 lb-ft., is to be operated by a 3-phase induction motor. Each of the following 3-phase induction motors has the proper potential, frequency, and speed rating. Each is arranged to be started with one-half of the rated potential by means of a compensator. The full-load torque of motor A is 310 lb.-ft.

	Motor A	Motor B
Stator effective resistance	0.0724 ohm	0.0355 ohm
Rotor ohmic resistance	0.0724 ohm	0.0592 ohm
Rotor effective resistance	0.109 ohm	0.178 ohm
Rotor leakage reactance	0.271 ohm	0.237 ohm
Stator leakage reactance	0.272 ohm	0.237 ohm
Slip at full load	0.03	0.025

All constants are referred to the stator. Neglect the drop due to the exciting current. Which of the two motors should be chosen and why?

73. A 3-phase, Y-connected, 2200-volt, 60-cycle, 44-pole induction motor, at the instant of starting, develops an internal torque of 792 lb-ft. when the applied potential and frequency are, respectively, 500 volts and 60 cycles. Under these conditions, the current is 152 amp., and the power consumed is 40.1 kw. At no load, the motor takes 13.5 kw. and 39.8 amp. per terminal when rated potential and frequency are impressed. What is (*a*) the rotor effective resistance per phase referred to the stator, (*b*) the stator effective resistance per phase, (*c*) the breakdown torque of the motor at rated frequency and potential?

At starting, the exciting current may be neglected, but do not neglect it under running conditions. Assume that the rotor and stator reactances at rated frequency are in the same ratio as the rotor and stator effective resistances.

74. What resistance should be connected across the rotor slip rings of motor S, W, X, Y, or Z in order to obtain the greatest possible starting torque for any given applied potential? What will be the starting current and power factor if 0.50 of rated line potential is applied to the motor under this condition?

75. What is the pull-out torque of motor Q, . . . T, . . . or Z?

76. What resistance must be connected across the rotor slip rings of motor S, W, X, Y, or Z in order to obtain full-load torque at the instant of starting with normal line potential applied to the motor? What will be the starting current and power factor for the condition?

77. What potential should be applied to motor Q, . . . T . . . or Z in order to obtain 0.50 of full-load torque at the instant of starting? What will be the starting current and power factor for this condition?

78. Compute the following for motor Q, . . . T, . . . or Z: (*a*) At what slip will the motor break down? (*b*) What is the torque in pound-feet during the given blocked test? (*c*) Compare the effect on the slip at breakdown of doubling the rotor resistance and of doubling the stator resistance. (*d*) What would be the effect on the breakdown torque of a drop of 5 per cent in the line potential? (*e*) If started with one-half of rated line potential applied, what is the greatest torque that can be obtained? What must be done to obtain this torque?

79. Draw the circle diagram for motor A. (*a*) What are the full-load power factor, slip, and efficiency? (*b*) What is the breakdown torque? (*c*) At what load is the power factor a maximum?

80. Draw the circle diagram for motor B. What are (*a*) the power factor, the slip, and the efficiency at full load, (*b*) at one-half of full load? (*c*) What is the breakdown torque? (*d*) At what load is the power factor a maximum?

81. Draw the circle diagram for motor C. (*a*) What are the power factor, the slip, and the efficiency at full load? (*b*) What is the breakdown torque? (*c*) At what load is the power factor a maximum?

82. Draw the circle diagram for motor D. What are (*a*) the power factor, the slip, and the efficiency at full load, (*b*) at one-half full load? (*c*) What is the breakdown torque?

83. Draw the circle diagram for motor E. (*a*) What are the power factor, the slip, and the efficiency at full load? (*b*) What is the breakdown torque? (*c*) At what load is the power factor a maximum?

84.[1] The following data are given on a 5-hp., 110-volt, 8-pole, 60-cycle, 3-phase induction motor. The stator and rotor windings are both connected in Δ, and the former has an effective resistance of 0.24 ohm and a leakage reactance of 0.70 ohm per phase. The ohmic resistance of the rotor winding referred to the stator is 0.36 ohm per phase. At no load, the motor takes 300 watts at 110 volts and a power factor of 0.15. When this motor takes 5100 watts at 110 volts and a power factor of 0.835, what are the slip, the power output, and the torque?

85.[2] A 3-phase, 1000-hp. induction motor is taking 916 kw. from a 2200-volt circuit at a power factor of 0.914. At no load, with an impresssed potential of 2200 volts, the line current is 75.1 amp., and the power is 15.2 kw. The effective resistance and the leakage reactance of the stator winding, which is Y-connected, are 0.118 and 0.32 ohm per phase. The ohmic resistance of the rotor winding referred to the stator is 0.10 ohm per phase. What is the output for the specified load? What is the slip?

86.[2] A 3-phase, 2600-hp. induction motor is taking 2272 kw. from a 6470-volt circuit, and the line current is 245 amp. At no load, with a line potential of 6400 volts, the line current is 89.5 amp., and the power is 47.5 kw. The ohmic resistance of the stator winding between terminals is 0.561 ohm at 25°C. The ohmic resistance of the open-circuited rotor winding between terminals is 0.0766 ohm at 25°C.[3] The leakage reactance of the stator winding is 3.64 ohms between terminals. With the rotor blocked, 375 kw. is supplied when the line current is 369 amp. The temperature of the windings at this time is 25°C. Assume that the ratios of effective resistance to ohmic resistance are the same for the stator and rotor windings at 25°C. What is the output for the specified load? What is the slip? What

[1] Use either the transformer diagram or the equivalent circuit in the solution of this problem.

[2] Use either the transformer diagram or the equivalent circuit in the solution of this problem. See R. R. Lawrence, "Principles of Alternating Current Machinery," p. 454.

[3] For ratio of transformation, see motor J, p. 211.

is the distribution of the losses? The temperature at this time is 73°C.

87.[1] A 3-phase, 2000-volt, 60-cycle induction motor has a full-load capacity of 500 hp. The stator winding has an effective resistance of 0.36 ohm and a leakage reactance of 1.1 ohms per phase. The rotor winding has an ohmic resistance of 0.157 ohm and a leakage inductance of 1.96 mil-henrys per phase referred to the stator. Both of the windings are connected in Y. The magnetizing current is 23 amp., the core loss is 2470 watts, and the friction and windage loss is 11 kw. What are the slip, the power factor and the efficiency when the motor delivers its rated output?

88.[1] A 3-phase, 1900-volt, 22.5 cycle, 36-pole induction motor has a full-load capacity of 570 hp. The ohmic resistances of the stator and rotor windings are 0.488 and 0.0138 ohm per phase, and their effective resistances at the rated frequency are, respectively, 1.4 and 1.6 times as great. Both of the windings are connected in Δ, and the ratio of transformation of stator to rotor is 6:1. The magnetizing component of the line current is 57.2 amp., the core loss is 2.8 kw., and the friction and windage loss is 12 kw. With the rotor blocked, the line current is 200 amp. when the impressed potential is 600 volts. Assume that the ratios of leakage reactance to effective resistance at the rated frequency are the same for both stator and rotor windings.

What are the slip, the power factor, and the efficiency when the motor delivers its rated output?

89.[1] A 3-phase, 500-volt, 38-cycle, 6-pole railway induction motor has a full-load capacity of 120 hp. The ohmic resistances of the stator and rotor windings are 0.04 and 0.01 ohm per phase, and their effective resistances at the rated frequency are, respectively, 1.45 and 1.60 times as great. Both of the windings are connected in Y, and their ratio of transformation is 2:1. The magnetizing component of the line current is 34 amp., and the total no-load losses are 4400 watts. With the rotor blocked, the line current is 800 amp. when the applied potential is 500 volts. Assume that the leakage reactances of the stator and rotor windings at the rated frequency are equal

[1] Use either the transformer diagram or the equivalent circuit in the solution of this problem. See R. R. Lawrence, "Principles of Alternating Current Machinery," p. 454

when reduced to the same side. What are the slip, the power factor, and the efficiency when the motor delivers a torque of 1200 lb.-ft.?

90.[1] The full-load capacity of a 3-phase, 2000-volt, 50-cycle induction motor is 335 hp. The motor is wound for 6 poles, and both the stator and rotor windings are connected in Y. The effective resistance of the stator winding is 0.23 ohm, and the ohmic resistance of the rotor winding referred to the stator is 0.203 ohm per phase. At 50 cycles, the leakage reactances of the stator and rotor windings, referred to the stator, are, respectively, 0.70 and 0.83 ohm per phase. At no load, the motor takes 15.2 amp. from a 2000-volt circuit at a power factor of 0.187. The core loss is 7400 watts at this time. The motor is operating with a slip of 1.43 per cent, and the terminal potential has its rated value. What is the output of the motor? What is the power factor? What is the efficiency?

91.[1] A 3-phase, 500-volt, 38-cycle railway induction motor has a full-load capacity of 150 hp. The ohmic resistances of the stator and rotor windings are 0.052 and 0.013 ohm per phase, and the effective resistances are, respectively, 1.40 and 1.55 times as great at the rated frequency. The motor is wound for 8 poles. Both stator and rotor windings are connected in Y and have a ratio of transformation of 9:5. At no load, with an applied potential of 500 volts, the motor takes a current of 46.6 amp. at a power factor of 0.141. With the rotor blocked, the motor takes a current of 610 amp. when the line potential is 500 volts. Assume that the leakage reactances are in the same ratio as the effective resistances at the rated frequency. What are the slip, the power factor, and the efficiency when the motor delivers a torque of 1950 lb.-ft.?

92.[1] At no load, when the line potential has its rated value of 1900 volts, a 3-phase, 570-hp. induction motor takes a line current of 57.2 amp. at a power factor of 0.091. The speed of the rotor is 74.6 r.p.m., and the slip is 1 revolution in 23 min. The ohmic resistances of the stator and rotor winding are 0.488 and 0.0138 ohm per phase. The motor is wound for 36 poles, and both the stator and the rotor windings are connected in Δ and have a ratio of transformation of 6:1. With the rotor blocked, the line current is 200 amp., and the power supplied

[1] Use either the transformer diagram or the equivalent circuit in the solution of this problem.

is 59.2 kw. when the line potential is 600 volts. Assume that the ratios of effective to ohmic resistance are the same for the stator and rotor and that the ratios of leakage reactance to effective resistance are also the same for each winding.

What is the friction and windage loss? What is the core loss?

93.[1] A 3-phase, 2000-volt, 60-cycle induction motor is rated to deliver 500 hp. at full load. The ohmic resistances of the stator and rotor windings are, respectively, 0.24 and 0.0153 ohm per phase, and the ratios of effective to ohmic resistance are, respectively, 1.5 and 1.6. With the rotor blocked, the power factor is 0.29. Assume that the ratios of leakage reactance to effective resistance at the rated frequency are the same for the stator and rotor. The motor is wound for 44 poles, and both the stator and rotor windings are connected in Y and have a ratio of transformation of 16:5. The friction and windage loss 11.0 kw., and the core loss is 2470 watts at the rated potential.

With the line potential adjusted so that the e.m.f. generated in the stator winding by the air-gap flux is 1120 volts per phase, what is the slip in r.p.m. at no load? What are the line potential, the current, and the power for this condition?

94.[1] The full-load capacity of a 3-phase, 980-volt, 20-cycle induction motor is 200 hp. The effective resistance and leakage reactance of the stator winding are 0.342 ohm and 1.08 ohms, respectively. The ohmic resistance and leakage inductance of the rotor winding referred to the stator are 0.141 ohm and 5.1 mil-henrys. The motor is wound for 24 poles, and both the stator and rotor windings are connected in Δ. At no load, the motor takes a line current of 39.4 amp. and absorbs 6680 watts when the applied potential has its rated value. The friction and windage loss is 4.0 kw. If the air-gap flux is assumed to be constant, the maximum torque occurs when the slip equals the ratio of the resistance of the rotor winding to its leakage reactance at the rated frequency. In this case, how much must the applied potential be increased in order that the air-gap flux will have its no-load value when the torque is a maximum?

[1] Use either the transformer diagram or the equivalent circuit in the solution of this problem.

		F	G	H	I	J
Horsepower		50	150	500	1,000	2,600
Line potential		2,200	500	2,200	2,200	6,400
Frequency		60	60	25	25	25
Connection		Y	Δ			
Poles		......	......	12	12	36
Ohmic resistance between terminals:						
Stator		6.307	0.050	0.357	0.130	0.561
Rotor		......	......	0.0286	0.0772	0.0766
At temperature		hot	hot	25°C.	25°C.	25°C.
Ratio of transformation		......	......	2,200:610	2,200:1,500	6,400:2,076
No load, temperature 25°C.	Potential, line	2,200	500	2,200	2,200	6,400
	Current, line	4.14	36.7	39.9	75.1	89.5
	Power	1,620	7,550	13,600	15,200	47,500
Blocked, temperature 25°C.	Potential, line	620	80	750	400	2.200
	Current, line	25	245	288	346.5	369
	Power	10,600	12,500	116,000	68,000	375,000

95.[1] What are the power factor, the output, and the efficiency of the induction motor F when the slip is 1.55 per cent? Assume that the ratios of effective to ohmic resistance are, respectively, 1.1 and 1.20 for the stator and rotor windings and that the leakage reactances are equal when reduced to the same side.

96.[1] What are the slip, the power factor, and the efficiency of the induction motor G when it delivers full load and the e.m.f. generated in the stator winding by the air-gap flux is the same as at no load? Assume that the ratios of effective to ohmic resistance are, respectively, 1.4 and 1.6 for the stator and rotor windings and that the ratio of the leakage reactances at the rated frequency is equal to the ratio of the effective resistances.

97.[1] What are the power factor, the torque, and the efficiency of the induction motor H when the slip is 1.86 per cent? Assume that the ratios of effective to ohmic resistance are the same for the stator and rotor windings at 25°C. and that the ratio of the ohmic resistances is equal to the ratio of the leakage reactances of the two windings at the rated frequency. The temperature under the running condition is 65°C.

98.[1] What are the power factor, the slip, and the efficiency of the induction motor I when it delivers a torque of 22,000 lb.-ft.? Assume that the ratios of the ohmic and effective resistances and the leakage reactances of the stator and rotor windings are equal at the rated frequency and a temperature of 25°C. The running temperature is 70°C.

[1] Use the transformer diagram in the solution of this problem.

99.[1] What are the power factor, the slip, and the efficiency when the induction motor J delivers 2750 hp.? Assume that the ratio of the effective to the ohmic resistance for the rotor is 20 per cent greater than for the stator and that the ratios of the leakage reactances and of the effective resistances are equal at the rated frequency and a temperature of 25°C. The running temperature is 70°C.

100. What are the power factor, the torque, and the efficiency for the induction motor I when the slip is 1.6 per cent and the line potential has its rated value? Make the same assumptions in regard to the resistances and reactances as were made in problem 98.

101. What are the power factor, the slip, and the efficiency when the induction motor J delivers a torque of 164,000 lb.-ft. and the line potential is 6400 volts? Make the same assumption in regard to the resistances and reactances as were made in problem 99.

102. What are the power factor, the slip, and the efficiency when the induction motor H delivers 560 hp. and the impressed potential has its rated value? Make the same assumption in regard to the resistances and reactances as were made in problem 97.

103.[2] What are the power factor, the output, and the efficiency of induction motor Q, . . . T, . . . or Z when the slip is 1.5 per cent?

104.[2] What are the slip, the power factor, and the efficiency of induction motor Q, . . . T, . . or Z when it delivers full load and the e.m.f. generated in the stator winding by the air-gap flux is the same as at no load?

105.[2] What are the slip, the power factor, and the efficiency of induction motor Q, . . T, . . . or Z when it delivers (*a*) one-quarter, (*b*) one-half, (*c*) three-quarters, (*d*) full load with normal potential applied at the terminals?

106.[2] What will be the effect on the power factor, the efficiency, and the slip of induction motor Q, . . . T, . . . or Z if the frequency only of the applied potential is (*a*) reduced 5 per cent, (*b*) increased 5 per cent under the condition that the rotor copper loss shall have its full-load value?

[1] Use the transformer diagram in the solution of this problem.

[2] Assume that the ratios of effective to ohmic resistance are the same for stator and rotor windings and that the leakage reactances are equal when reduced to the same side.

107.[1] What will be the effect on the power factor, the efficiency, and the slip of induction motor Q, . . . T, . . . or Z if the magnitude only of the applied potential is (*a*) reduced 5 per cent, (*b*) increased 5 per cent under the condition that the rotor copper loss shall have its full-load value?

108. Two 3-phase, 220-volt, 60-cycle induction motors are connected in concatenation across a 220-volt circuit. Each is rated to deliver 10 hp. and is wound for 6 poles. What is the no-load speed? When they deliver 10 hp., what is the torque developed by each motor?

109. Two 3-phase, 220-volt, 60-cycle induction motors are connected in concatenation across a 220-volt circuit. Each is rated to deliver 10 hp., but one is wound for 6 poles, and the other for 8 poles. What is the no-load speed? When they deliver 10 hp., what is the torque developed by each motor? What per cent of its full-load current does each motor carry?

110. Two 3-phase, 220-volt, 60-cycle induction motors are connected in concatenation across a 220-volt circuit. One is rated to deliver 10 hp., and the other 15 hp., but both are wound for 6 poles. What is the no-load speed? What load is delivered when the 15-hp. motor takes its full-load current? What per cent of its full-load value is the current in the 10 hp. motor? What is the torque developed by each?

111. Two 3-phase, 220-volt 60-cycle induction motors are connected in concatenation across a 220-volt circuit. One is rated to deliver 10 hp. and is wound for 6 poles, and the other is rated to deliver 15 hp. and is wound for 4 poles. What is the no-load speed? What is the greatest load that can be delivered and have neither motor take more than its full-load current? When they deliver 15 hp., what torque does each develop?

112. The two induction motors M and P are connected in concatenation. The stator of the first receives power at its rated potential and frequency, and the stator of the second is short circuited. Neglect the no-load component of the current and the core loss due to the leakage flux. What is (*a*) the total output when the slip of the first motor is 51.3 per cent, (*b*) the power developed by each motor? (*c*) What are the copper losses in the stator and rotor of each motor?

[1] Assume that the ratios of effective to ohmic resistance are the same for stator and rotor windings and that the leakage reactions are equal when reduced to the same side.

INDUCTION-MOTOR DATA

Number	K	L	M	N	P
Horsepower	500	570	150	150	120
Line potential	2,000	1,900	500	500	500
Connection, both stator and rotor	Y	Δ	Y	Y	Y
Frequency	60	22.5	38	38	38
Poles	44	36	6	8	6
Magnetizing current, per phase[1]	23	33	45	46	34
Core loss at no load[1, 2]	2,470	2,800	1,300	1,360	1,200
Ohmic resistance per phase					
Stator	0.24	0.488	0.054	0.052	0.04
Rotor	0.0153	0.0138	0.014	0.013	0.01
Ratio of effective resistance to ohmic resistance at the rated frequency					
Stator	1.3	1.35	1.25	1.25	1.2
Rotor	1.4	1.55	1.4	1.35	1.4
Leakage inductance phase, millihenrys					
Stator	2.6	13	0.091	0.086	0.68
Rotor	0.17	0.37	0.024	0.022	0.18
Ratio of transformation	16.5	6.1	15.7	9.5	2.1

[1] At the rated potential.

[2] Assume that the ratio of the core loss in the stator to that in the rotor for the same mean flux density and frequency is 4 : 3.

113. The two induction motors N and P are connected in concatenation. The stator of the first receives power at its rated potential and frequency, and the stator of the second is short circuited. Neglect the no-load component of the current and the core loss due to the leakage flux. Assume that the core loss due to the mutual flux varies as the product of the frequency and the square of the flux density. What is (*a*) the total output when the slip of the second motor is 4.0 per cent, (*b*) the power developed by each motor? What are (*c*) the copper losses in the stator and rotor of each motor, (*d*) the core losses in the stator and rotor of each motor?

114. The two induction motors M and N are connected in concatenation. The stator of the first receives power at its rated potential and frequency, and the stator of the second is short circuited. Neglect the no-load component of the current. Assume that the loss caused by the leakage flux varies as the frequency and the square of the current. Assume that the core loss due to the mutual flux varies as the product of the frequency and the square of the flux density. What is (*a*) the total output when the speed is 228 r.p.m., (*b*) the power developed by each motor? What are (*c*) the effective resistance losses in the stator and rotor of each motor, (*d*) the core losses in the stator and rotor of each motor?

115. The two induction motors K and L are connected in concatenation. The stator of the first receives power at its rated potential and frequency, and the stator of the second is short circuited. Neglect the no-load component of the current. Assume that the loss caused by the leakage flux is proportional to the frequency and the square of the current. Assume that the core loss due to the mutual flux varies as the frequency and the square of the flux density. What is (*a*) the total output when the slip of the second motor is 1.55 per cent, (*b*) the power developed by each motor? What are (*c*) the effective resistance losses in the stator and rotor of each motor, (*d*) the core losses in the stator and rotor of each motor?

116. The two induction motors M and P are connected in concatenation. The stator of the first receives power at its rated frequency, and the stator of the second is short circuited. Do not neglect the no-load component of the current, but assume that it is proportional and wattless with respect to the generated e.m.f. Assume that the loss caused by the leakage flux varies as the frequency and the square of the current. Assume that the core loss due to the mutual flux varies as the product of the frequency and the square of the flux density. (*a*) What is the total output when the speed is 368 r.p.m. and the e.m.f. generated by the air-gap flux in the rotor winding of the second motor is 68 volts per phase? (*b*) What power do they receive from the line, and at what power factor do they operate? (*c*) What is the power developed by each motor?

117. The two induction motors K and L are connected in concatenation. The stator of the first receives power at its rated frequency, and the stator of the second is short circuited. Do not neglect the no-load component of the current, but assume that it is proportional and wattless with respect to the generated e.m.f. Assume that the loss caused by the leakage flux varies as the frequency and the square of the current. Assume that the core loss due to the mutual flux varies as the product of the frequency and the square of the flux density. (*a*) What is the total output when the slip of the second motor is 1.55 per cent and the e.m.f. generated by the air-gap flux in the rotor winding of this motor is 430 volts per phase? (*b*) What power do they receive from the line, and at what power factor do they operate? (*c*) What is the power developed by each motor?

118. A 1000-hp. induction motor is operated as an induction generator in parallel with a synchronous generator having a full-load capacity of 1000 kv.-a. The induction machine, which is wound for 12 poles, is driven at a constant speed of 250.5 r.p.m. The speed of the synchronous generator falls uniformly from 1530 r.p.m. at no load to 1500 r.p.m. at full load, when the frequency is 25 cycles. The load delivered by the induction generator is proportional to the slip, which at full load is 1.7 per cent. When the total load supplied is 1500 kw., what is the load delivered by each? At what speed should the induction generator be driven so that both will deliver their rated loads at the same time?

119. An induction generator and a synchronous generator, each rated to deliver 2500 kv.-a., are operated in parallel. The speed of the induction generator falls from 1520 at no load to 1498 at full load, and the speed of the synchronous generator falls from 1525 at no load to 1490 at full load. The load on the induction generator is proportional to the slip which at full load is 1.8 per cent. What is the greatest load that can be delivered without overloading either generator? To what value should the full-load speed of the synchronous generator be adjusted so that both generators will deliver their rated loads at the same time?

120. A 4-pole induction generator and a 2-pole synchronous generator are operating in parallel. The induction generator is driven at a constant speed, but the speed of the synchronous generator falls from 3660 r.p.m. at no load to 3590 at full load of 2000 kw. The resistance of the rotor windings between terminals referred to the stator is 0.73 ohm. Neglect the stator resistance and reactance, the rotor reactance, and the losses. The excitation of the synchronous generator is adjusted so that the terminal potential is 6400 volts at all loads. The speed of the induction generator is adjusted so that when the synchronous machine is delivering no power, the load on the induction generator is 500 kw. What is the division of the load when 3500 kw. is delivered? What is the frequency at this time? At what speed should the induction generator be driven so that both will deliver their rated loads, *viz*, 2000 kw., at the same time?

121. A 500-kw., 3-phase induction generator is operated with a synchronous motor floated across its terminals. At no load, when running as an induction motor, it takes a line current of

31 amp. at 2000 volts. The resistance of the rotor winding between terminals is 0.0228 ohm, and the ratio of transformation from stator to rotor is 16:5. Neglect the resistance and reactance of the stator and the reactance of the rotor windings of the induction generator and all of the losses in both machines. The excitation of the synchronous motor is adjusted so that the terminal potential is 2000 volts. The load supplied by these machines is 450 kw. at a power factor of 85 per cent. What is the line current supplied by the induction generator? What is the frequency of this system if the induction generator is wound for 44 poles and is driven at 165 r.p.m.? If the synchronous motor has a synchronous reactance of 6.2 ohms between terminals, what is its necessary excitation e.m.f.?

122. An induction generator supplies power to a load and to an overexcited synchronous motor. At no load as an induction motor it takes a line current of 98 amp. at 2200 volts. The resistance of the rotor winding between terminals is 0.058 ohm, and the ratio of transformation from stator to rotor is 22:15. Neglect the resistance and reactance of the stator winding and the reactance of the rotor winding of the induction generator and all of its losses. The rotational losses of the synchronous motor are 23.3 kw., and the resistance and synchronous reactance are, respectively, 0.26 and 3.04 ohm between terminals. The induction generator delivers 1150 kw. of which the synchronous motor receives 450 kw. The excitation of the latter is adjusted so that the terminal potential is 2200 volts. The power factor of the load exclusive of the synchronous motor is 0.83. The induction generator is wound for 12 poles and is driven at a speed of 254 r.p.m. What is the frequency of the system? At what power factor is the synchronous motor operating? What is the excitation e.m.f. of the synchronous motor? What is the power output of the synchronous motor?

123. A 2000-kw. induction generator is operated in parallel with a synchronous generator of the same capacity. At no load, when running as an induction motor, it takes a line current of 90 amp. at 6400 volts. The resistance of the rotor winding between terminals is 0.0766 ohm, and the ratio of transformation from stator to rotor is 6400:2076. Neglect the resistance and reactance of the stator and the reactance of the rotor winding and all of its losses. The resistance and synchronous reactance of the synchronous generator between terminals are, respec-

tively, 0.65 ohm and 14.2 ohms. The induction generator delivers 1800 kw., and the synchronous generator 1200 kw. The excitation of the latter is adjusted so that the terminal potential is 6400 volts. The power factor of the load is 0.85. The induction generator is wound for 36 poles and is driven at a speed of 82.4 r.p.m. What is the frequency of the system? At what power factor does the synchronous generator operate? What is the excitation e.m.f. of the synchronous generator?

124. An induction generator is supplying power to a synchronous motor. The induction generator is driven at a constant speed of 250 r.p.m. The line potential is 2200 when the synchronous motor is fully loaded. Compute the speed regulation of the synchronous motor from no load to full load. Indicate clearly all approximations. Data for the two machines are as follows:

SYNCHRONOUS MOTOR

Rated line potential	2200
Rated frequency	25 cycles
Full-load output	1000 hp
Rotational losses, assumed constant	17.2 kw.
Armature connection	Y
Effective armature resistance per phase	0.172 ohm
Synchronous reactance, per phase[1]	3.79 ohms

INDUCTION GENERATOR

Rated line potential	2200
Full-load output	750 kw.
Core loss, assumed constant	15.2 kw.
No-load current, running as motor, 2200 volts, 25 cycles	75.1 amp.
Connections, stator and rotor	Y
Stator constants[1]	
Effective resistance, per phase	0.0752 ohm
Leakage reactance, per phase	0.277 ohm
Rotor constants, referred to stator[1]	
Effective resistance, per phase	0.0948 ohm
Ohmic resistance, per phase	0.0815 ohm
Leakage reactance, per phase	0.347 ohm
Number of poles	12

[1] Assume that all constants are given at 25 cycles

125. An induction generator and a synchronous generator are operated in parallel and supply a load of 700 kw. at 0.86 power factor. Data concerning the induction generator are 370 kw., 2000 volts, 44 poles, Y wound. The stator resistance is 0.32

ohm per phase, and the rotor resistance is 0.166 ohm per phase referred to the stator. The stator and rotor leakage reactances at normal frequency are, respectively, 0.98 and 0.66 ohm per phase. The magnetizing current is 23 amp. at the rated potential, and the core loss is 2.47 kw. Data concerning the synchronous generator are 500 kw.; 2200 volts; 64 poles; Y wound. The effective resistance and synchronous reactance of the armature winding are, respectively, 0.224 ohm and 2.76 ohms per phase. The induction generator is driven at 166.4 r.p.m., and the synchronous generator at 113.0 r.p.m. What is the division of the load if the excitation of the synchronous machine is adjusted so that the terminal potential is 2200 volts? What is the necessary excitation e.m.f. of the synchronous generator?

126. An induction generator and a synchronous generator are operated in parallel and supply a load of 950 kw. at 0.83 power factor. Data concerning the induction generator are 450 kw., 2000 volts, 36 poles, Δ wound. The magnetizing current is 33 amp. per phase, and the core loss is 2.8 kw. The stator and rotor resistance referred to the stator are 0.66 and 0.50 ohm, respectively. The stator and rotor leakage reactances at normal frequency referred to the stator are 0.184 and 0.188 ohm, respectively. Data concerning the synchronous generator are 850 kw., 2000 volts, 32 poles, Y wound. The effective resistance and synchronous reactance are, respectively, 0.064 ohm and 2.40 ohms per phase. The induction generator is driven at 85.0 r.p.m., and the synchronous generator at 94.0 r.p.m. What is the division of the load if the excitation of the synchronous generator is adjusted so that the terminal potential is 2000 volts? What is the necessary excitation e.m.f. of the synchronous generator?

127. An induction generator and a synchronous generator are operated in parallel and supply an inductive load of 1400 kw. at 0.86 power factor. The data for the induction generator are rating, 750 kw.; 2200 volts; 60 cycles; Y connected; 44 poles. Resistances and reactances per phase are referred to the stator. The reactances are both for the frequency at which the system operates in this problem. The ratios of the effective to the ohmic resistances are 1.3 for both the stator and rotor.

r_1 ohmic = 0.120 ohm	r_2 ohmic = 0.0784 ohm
x_1 = 0.493 ohm	x_2 = 0.330 ohm

Under operating conditions, the magnetizing component of the no-load current is 46.0 amp., and the core-loss component is 1.56 amp. The synchronous generator has 64 poles and is driven at a speed of 113.0 r.p.m. The terminal potential is 2200 volts. If the induction generator is driven at a speed of 166.4 r.p.m., at what power factor will the synchronous generator operate?

128. Induction motor H[1] is operated as a generator in parallel with a synchronous generator. There is an inductive load on the system of 800 kw. at 0.95 power factor. The frequency and line potential of the system are maintained at 25 cycles and 2200 volts by the synchronous generator. What is the power factor of each machine, and what load does the induction generator carry when it receives 440 kw. from its prime mover?

Assume that the ratios of effective to ohmic resistances of the rotor and stator are the same and that the reactances are equal when referred to the stator. To simplify the computation, assume that the temperature under load is 25°C. Assume that the friction and windage and core losses are constant. The friction and windage loss is 7 kw.

129.[1] The induction motor G is operated as a generator on a 60-cycle circuit in parallel with synchronous apparatus. What are the slip, the power factor, and the efficiency when it receives 150 hp. from the prime mover and the terminal potential is 500 volts?

Assume that the ratios of effective to ohmic resistance are, respectively, 1.4 and 1.6 for the stator and rotor windings and that the ratio of the leakage reactances at the rated frequency is the same as ratio of the effective resistances.

130.[1] The induction motor H is operated as a generator on a 2200-volt, 25-cycle circuit in parallel with synchronous apparatus. What are the output, the power factor, and the efficiency when the slip is 1.86 per cent?

Assume that the ratios of effective to ohmic resistance are the same at 25°C. and that the ratio of the ohmic resistances is equal to the ratio of the leakage reactances of the two windings at the rated frequency. The temperature under the running condition is 65°C.

[1] See p. 211.

131.[1] The induction motor I is operated as a generator on a 25-cycle circuit in parallel with synchronous apparatus. What are the slip, the power factor, and the efficiency when it receives 1000 hp. from the prime mover and the terminal potential is 2200 volts?

Assume that the ratios of the ohmic resistances, the effective resistances, and the leakage reactances of the stator and rotor windings are equal at the rated frequency and a temperature of 25°C. The running temperature is 70°C.

132. Induction motor I (p. 211) is operated as an induction generator in parallel with the synchronous generator of problem 93 (p. 73), which is connected to the bus bars through three 333 kw. a. 13,800:1270-volt single-phase transformers. The short-circuit data for the transformers are volts, 413; amperes, 25.2 (approximate full-load current); watts, 2150.

The induction motor is Δ connected and has a friction and windage loss of 6 kw. Both the friction and windage and the core loss may be assumed constant. Assume that x_1 equals x_2 when referred to the same side and, also, that the ratios of ohmic to effective resistances are the same for both stator and rotor at the stator frequency. The system is operated at 25 cycles and 2200 volts at the bus bars and delivers 1500 kw. at 0.90 power factor to a combined induction motor and lighting load. The governor of the turbine driving the induction generator is so adjusted that the slip of the induction generator is 0.016. (*a*) How are the transformers connected? Compute (*b*) output of induction generator; (*c*) power factor of induction generator; (*d*) efficiency of induction generator; (*e*) output of synchronous generator; (*f*) power factor of synchronous generator (does the current lead or lag?); (*g*) excitation of synchronous generator. Assume that the resistances are all referred to 25°C., and compute the results for this temperature.

133.[1] The induction motor J is operated as a generator on a 6400-volt, 25-cycle circuit in parallel with synchronous apparatus. What are the output, the power factor, and the efficiency when the slip is 1.9 per cent? Assume that the ratio of the effective to the ohmic resistance for the rotor is 20 per cent greater than for the stator and that the ratios of the leakage reactances and of the effective resistances are equal at the rated frequency and a temperature of 25°C. The running temperature is 70°C.

[1] See p. 211.

INDUCTION-MOTOR DATA

Number	Q	R	S	T	U	V	W	X	Y	Z
Horsepower	10	15	40	50	100	100	300	400	1,000	1,000
Connection	Y	Y	Y	2-φ	Y	Y	Y	Δ	Y	Y
Stator circuits in parallel	2	3	series	2	4	3	2	1	4	7
Line potential	220	220	440	550	440	440	2 200	2,200	2,200	2,300
Frequency	60	60	60	60	60	60	60	25	60	60
Poles	6	6	8	8	8	12	16	6	16	14
Diameter at air gap, inches	8 206	10 0	14 25	17 5	17 5	26 5	40	33 5	57	62
Length of air gap, inches	0 022	0 025	0 031	0 032	0 039	0 040	0 045	0 06	0 0625	0 065
Length of core, inches	6 0	6 5	6 0	7 75	8 0	7 5	12	12 5	17	12
Stator slots	54	72	96	96	120	144	168	126	240	252
Rotor slots	77	89	72	117	94	114	240	108	192	336
Stator coil pitch, slots	7	9	9	9	14	9	8	14	14	13
Rotor coil pitch, slots	cage	cage	8	cage	cage	cage	15	18	12	24
Series conductors per slot										
Stator	20	36	8	20	14	12	18	20	12	24
Rotor	1	1	8	1	1	1	2	4	2	2
Resistance per phase, direct current										
Stator	0 196	0 104	0 158	0 185	0 052	0 048	0 26	1 23	0 0665	0 0607
Rotor			0 038				0 0145	0 0427	0 0252	0 0043
At temperature, degrees Centigrade	75	25	75	25	75	25	25	75	75	25
Ratio of transformation			1 0 80				5 25 1	1 0 189	1 0 516	4 18 1
No load: Volts	220	220	440	550	440	440	2,200	2 200	2 200	2,300
No load: Amperes	9 3	15 0	18 5	13 6	37 2	37 5	25 5	19 2	75 3	57 3
No load: Watts	430	620	1,360	1 650	2 800	2,920	5 400	7 000	24,500	23,700
Blocked: Volts	60	27 4	150	87	180	98 4	450	700	800	408
Blocked: Amperes	42	38 0	57	42	265	125	73	150	400	210
Blocked: Watts	2,200	955	2,800	3,000	3,200	7 820	12,500	150,000	90,000	20,000

If necessary assume that the friction and windage and the core losses are equal

TYPICAL SATURATION CURVE

Per Cent Normal Exciting Ampere-turns	Per Cent Normal Air-gap Flux Density
20 0	22 0
30 0	33 0
39 7	43 7
64 2	68 2
86 1	88 7
100	100
119 2	113 6
137 8	125 0
164 3	136 4

CHAPTER VI

EXAMINATION QUESTIONS

1. When the secondary winding of a certain air-core transformer is on open circuit and 100 volts at 60 cycles is impressed on the primary, the current is 20 amp. Under this condition, a voltmeter connected to the secondary indicates 40 volts. The primary resistance is 3 ohms, and the ratio of the number of turns in the primary and secondary windings is $N_1:N_2 = 2$. What is (*a*) the self-inductance of the primary winding, (*b*) the primary leakage inductance, (*c*) the mutual inductance between the primary and secondary windings?

2. An air-core transformer has the following constants at 500 cycles:

$\omega L_1 = 237.9$ ohms $r_1 = 33.2$ ohms
$\omega L_2 = 60.7$ ohms $r_2 = 16.6$ ohms
$\omega M = 59.1$ ohms

If a load of $Z = 400 + j300$ vector ohms is connected to the secondary, what will be the primary and secondary currents when the potential impressed on the primary is 100 volts at 500 cycles?

3. What determines the mutual flux in a transformer? How does the mutual flux vary with the load? How would it be affected by doubling both the primary and the secondary turns, keeping the frequency and the impressed potential the same? If, when the turns are doubled, the cross-section of the core is halved, how will the exciting current be affected? Explain why the wave forms of the terminal e.m.fs. on both the primary and secondary sides of a transformer of usual design are almost exactly the same no matter what the character of the load. Why does the wave form of the no-load current of a transformer differ from the wave form of the impressed potential?

4. In a given transformer, the ratio of eddy current to hysteresis loss is 1:3 with normal applied potential and frequency.

What would be the effect on the core losses of increasing by 5 per cent (*a*) the applied potential, (*b*) the frequency of the applied potential, (*c*) the turns in both windings, (*d*) the cross-section of the magnetic circuit, (*e*) the length of the magnetic circuit?

5. Explain why 25-cycle transformers are heavier and cost more than 60-cycle transformers. What conditions must be fulfilled in order that transformers may be operated successfully in parallel? Explain the necessity for each.

6. A 60- and a 30-cycle transformer operate at the same potential and the same flux density. The 60-cycle transformer has 200 turns in its primary winding and has a core 3 in. square. Its magnetizing current is 3 amp. If the ratios of the cross-sections of the cores and of the turns in the windings of the two transformers are equal, (*a*) how many turns are there in the primary winding of the 30-cycle transformer, (*b*) what is the cross-section of its core? (*c*) If the mean length of the core of the 30-cycle transformer is 1.42 times that of the 60-cycle transformer, what is its magnetizing current?

7. On open circuit a 50-cycle, 2200:220-volt, 50-kv.-a. transformer circuit takes 800 watts at the rated potential. When the low-tension side of this transformer is short circuited and 115 volts at 60 cycles are impressed on the high-tension side, the current and power taken from the mains are 20 amp. and 1400 watts, respectively. Three-fourths of the core loss at rated potential and frequency is hysteresis loss. What is the all-day efficiency of this transformer when operating on a 1100-volt, 25-cycle circuit with the following non-inductive loads on the low-tension side: 1 hour, 250 amp.; 2 hours, 100 amp.; 3 hours, 50 amp.; 18 hours, 0 amp.?

8. Three transformers are to be used to transform 3750 kv.-a. from 30,000 volts, 3-phase, to 2300 volts, 3-phase. (*a*) If these transformers are connected in Δ on the high-tension side and in Y on the low tension side, what must be the current and potential ratings of the primary and secondary windings? (*b*) What must be the primary and secondary current and potential ratings of two transformers connected in V which will produce the same transformation? Neglect the exciting currents and the leakage impedances of the transformers. (*c*) What is the total kilovolt-ampere transformer capacity, *i.e.*, the algebraic sum of the individual capacities of the transformers, for such connection?

9. In order to transform power from a 13,200-volt supply circuit to 440 volts, two transformers are connected in series. The first has a ratio of 13,200:2200, and the second a ratio of 2200:440. Each of these transformers has a 0.6 per cent resistance drop and a 4 per cent reactance drop with full-load current. What is the potential regulation of the combination for full-load kilovolt-amperes at 0.8 power factor?

10. In some experimental work, there is a demand for 1000 amp. at about 100 volts and at a power factor of 0.1 (lagging). The available source is at 1100-volts at 60 cycles. The available transformers are

Number	Kilovolt-amperes	Ratio	Frequency	Core loss[1]	Short-circuit data		
					Volts	Amperes	Watts
A............	100	2,200:220	60	940	120	45.5	1,050
B............	100	1,100:110	25	980	51	91	1,000
C............	100	2,200:220	25	920	105	45.5	990
D............	50	1,100:110	60	508	70	45.5	560

[1] Eddy currents cause 25 per cent of core loss.

Which transformer can be safely used for this work? At what potential would the 1000 amp. be supplied? What is the greatest current that can be drawn from the transformer without exceeding its rated full-load loss?

11. What must be the primary and secondary current and potential ratings for transformers necessary to convert 1000 kv.-a., 3-phase, from 60,000 volts between line conductors to 2300 volts between conductors when the transformers are connected (*a*) Δ on primary and secondary sides, (*b*) Y on primary and secondary sides, (*c*) Δ on primary side and Y on secondary side, (*d*) V on each side, (*e*) T on each side? Tabulate results in the following manner:

$V_1 =$ $\qquad\qquad$ $I_1 =$

$V_2 =$ $\qquad\qquad$ $I_2 =$

Indicate how ratings were obtained.

12. Three identical single-phase transformers, each rated at 400 kv.-a., 60 cycles, and 10,000:2000 volts, are connected in Δ on their primary and secondary sides. The primary impressed potentials are balanced and are each 10,000 volts. The open and short-circuit data for the transformers are

Open circuit			Short circuit		
Volts	Amperes	Watts	Volts	Amperes	Watts
2,000	3.0	2,700	325	40	3,000

(*a*) What is the greatest single-phase kilovolt-ampere load that can be supplied by the bank of transformers without overloading any one of them? (*b*) If a single-phase inductive load of 400 kw. and 0.8 power factor is applied to one phase of the secondaries of the transformers, what balanced 3-phase potentials must be impressed across the primaries in order to maintain 2000 volts across the secondary of the loaded phase? (*c*) What will be the potentials across the secondaries of each of the other two phases? Let the secondary potentials be V_{12}, V_{23}, and V_{31}, with V_{12} leading V_{23}. Let the load be applied across phase 1-2. Neglect the exciting current.

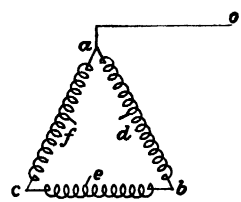


FIG. 21.

13. Three similar autotransformers having a ratio of transformation of 2:1 are connected in Δ across a 220-volt, 3-phase circuit. They deliver current to a balanced load. What is the relation in the magnitude and in the phase between the line current *oa* and the transformer current *ad*? (The currents I_{ad}, I_{be}, and I_{cf} are equal in magnitude and differ in phase by 120 deg.) See Fig. 21.

14. Determine the current in the windings of a 3-phase, 2-phase autotransformer bank when 100 kw.-a. is supplied to a balanced load. (*a*) 2300 volts 3-phase to 2300 volts 2-phase. (*b*) 2300 volts 3-phase to 3000 volts 2-phase. (*c*) 2300 volts 3-phase to 1800 volts 2-phase.

15. Determine the currents in the windings of a 100 kv.-a., 3-phase, Δ-connected autotransformer transforming from 4600 to 2300 volts by means of taps from the centers of the phases.

16. Determine the currents in the primary and secondary windings of a Δ-Δ connected bank of 22,000:2200-volt transformers having taps brought out from centers of the low-tension phases to give 1100 volts, (*a*) when supplying 500 kv.-a. at 0.80 power factor to a balanced load at 1100 volts, (*b*) when supplying 500 kv.-a. at 0.80 power factor at a balanced load at

1100 volts and with an additional balanced load of 500 kv.-a. at unity power factor and 2200 volts.

17. What do you understand by the *phase spread*, *breadth factor*, *pole pitch*, *coil pitch*, and *pitch factor?* What influence do the phase spread and coil pitch have on the magnitude and wave shape of the e.m.f. of an alternator? How does the radial depth of the air gap effect the regulation of an alternator? What determines the armature reaction of an alternator? Why is it necessary to provide with an amortisseur a 3-phase alternator which is to be operated single phase or on badly unbalanced loads? A 3-phase wave-wound alternator has 3 slots per pole per phase, with 4 inductors per slot; all inductors in each phase are connected in series. How would the potential, wave form, armature reactance, and rating of this alternator be affected by replacing the wave winding by a lap winding, with the same number of inductors per slot? By a spiral winding?

18. A 3-phase alternator has a phase potential of $e = 3290 \sin \omega t + 150 \sin 3\omega t + 100 \sin 5\omega t$. What will be the line potential of this generator when connected in Δ? When connected in Y? If three non-inductive resistances of 100 ohms each are connected in Δ across the terminals of the generator, what line current will be delivered by the generator when connected in Δ? What will be the line current when both the generator and this load are in Y (*a*) with neutrals connected, (*b*) without neutral connection?

19. The e.m.f. induced in each inductor in slot 1 of a 4-phase, 4-pole alternator, which has 3 slots per pole per phase and 4 inductors per slot, is

$$e = E \sin \omega t + \frac{E}{5} \sin\left(3\omega t - \frac{\pi}{6}\right) + \frac{E}{10} \sin\left(5\omega t + \frac{\pi}{6}\right).$$

The coil pitch of the alternator is five-sixths. What is the r.m.s. value of the e.m.f. between adjacent terminals of the alternator when (*a*) mesh connected, (*b*) star connected? (*c*) Will the armature copper loss be the same for star and mesh connection when the alternator furnishes 1000 kw. at 0.80 power factor to an induction load? Give reason for answer. (*d*) Will the wave form between adjacent terminals be the same at no load for star and mesh connection?

20. What effect do phase breadth and coil pitch have on the wave form of an alternator? The e.m.f. induced in a single

inductor of a 24-pole, 3-phase alternator, having 2 slots per pole per phase and 2 inductors in series per slot, is

$$e = E \sin pt + \frac{E}{5} \sin (3pt + 30°) + \frac{E}{10} \sin (5pt - 30°) + \frac{E}{10} \sin (7pt - 10°).$$

The coil pitch is five-sixths. What is the r.m.s. value of the terminal e.m.f. of this alternator when connected (*a*) in Y, (*b*) in Δ? Give the equation of the e.m.fs. for each connection. If the alternator is to furnish 100 kw. to a balanced Δ-connected, non-inductive load, will its armature copper loss be the same when connected in Y and in Δ? Explain.

21. The e.m.f. induced in a single inductor of a 24-pole 3-phase alternator having 2 slots per pole per phase, with 2 inductors per slot, is

$$e = E \sin \omega t + \frac{E}{5} \sin (3\omega t + 30°) + \frac{E}{10} \sin (5\omega t - 30°).$$

The coil pitch is five-sixths. Draw a diagram showing the positions of the coil sides for 30 space degrees of the armature surface. Let the upper coil side in slot 1 be in phase 1.

What is the r.m.s. value of the terminal e.m.f. of this alternator when it is connected (*a*) in Y, (*b*) in Δ? If this alternator furnishes 1000 kw. to a balanced 3-phase load at 0.8 power factor, will its armature copper losses be equal for both connections? The excitation of the alternator is the same in both cases. The load is Δ-connected in both cases. Will the wave form of the terminal potential be the same for the Y and Δ connections? If not, in what respect will it differ?

22. A 7500-kv.-a., 60-cycle, 3-phase, Y-connected alternating-current generator is rated to deliver power at 11,000 volts between terminals. The generator has 12 poles and 126 slots. There are 6 series conductors per slot, forming two coil sides; thus, each coil consists of 3 turns. The coil pitch is 9 slots. The winding is arranged so that the coil sides in the tops of the slots form belts of alternately 3 and 4 coil sides. This is, of necessity, also true of the coil sides in the bottom of the slots. With this arrangement, the conductors in the top of slots 3, 4, 5, 13, 14, 15, and 16 and those in the bottom of slots 1, 2, 3, 4, 12, 13, and 14 are in the same phase. What is the fundamental flux per pole in the air gap that will give a terminal potential of 11,000 volts at no load?

23. What factors influence the regulation of an alternator? What determines the relative magnitude of these factors? Why does the apparent resistance of a circuit carrying an alternating current differ from its ohmic resistance?

24. Two alternators have exactly the same measured regulation, but one has a much larger armature reaction and a much smaller armature reactance than the other. If the regulation of these two alternators is to be calculated, will the m.m.f. method or the synchronous-impedance method give the better results? Explain fully.

25. A 3-phase, 60-cycle, Δ-connected, 1000 kv.-a., alternator has a rated terminal potential of 6600 volts. The alternator has 32 poles, 192 armature slots with 24 series inductors per slot. The winding pitch is unity. The direct-current resistance between any pair of armature terminals is 1.05 ohms at operating temperature. The ratio of the effective to the ohmic armature resistance is 1.6.

The data for the open-circuit saturation curve, for the load saturation curve at zero power factor, and for the no-load core loss are given in the following table. All data are given at 60 cycles.

Field current, amperes	Open-circuit terminal potential, volts	Saturation curve at 87 amp. per terminal and zero power factor, volts	Open-circuit core loss, kilowatts
41.2	....	0	
50.0	4,400	....	7.5
.....	6,500	....	16.6
110.0	7,800	5,325	25.4
140.0	8,625	6,600	33.5
180.0	9,450	7,800	

The friction and windage loss at rated frequency is 7.0 kw. The rated field potential is 250 volts. What is (*a*) the regulation of the alternator, by the A.I.E.E. method, for rated kilovolt-ampere capacitive load at 6600 volts and 0.8 power factor, (*b*) the efficiency for the above load, (*c*) the armature equivalent leakage flux per ampere for each armature inductor?

26. (*a*) The open-circuit saturation curve of an alternator is given by the following points:

Per Cent of Rated Phase Potential	Per Cent of Normal Field Current
30	25
60	50
100	100
120	160

This alternator has a leakage reactance of 20 per cent (*i.e.* the leakage reactance drop with full-load current is 20 per cent of the rated phase potential). On short circuit with full-load armature current the field current is 80 per cent of its normal value. What is the field current when the alternator delivers full-load current at zero-power factor (lagging) and rated terminal potential? Use the Potier triangle method.

(*b*) The following data concerning an alternator are known: armature resistance, leakage reactance, synchronous reactance, and the open-circuit core-loss curve. Describe how to determine the core loss when this alternator delivers its rated current at unity power factor and its rated terminal potential.

(*c*) A 4-pole, 60-cycle alternator, operating in parallel with others, delivers its rated kilovolt-amperes at unity power factor. When steam is cut off from its prime mover, it becomes adjusted to its new condition of operation in 10 sec. By what per cent does the average speed of this alternator during these 10 sec. differ from synchronism (1800 r.p.m.)? The alternator has a synchronous reactance of 80 per cent.

27. The open-circuit and zero-power-factor (full-load-current) saturation curves of an alternator are given by the following data:

Field current	Open-circuit terminal volts	Terminal volts at zero power factor	Open-circuit core loss
41.2	......	0	
50	8,800	......	7,500
110	15,600	10,750	25,400
140	17,250	13,250	33,500
180	18,900	15,600	

Using (*a*) the Potier triangle method, construct the zero-power-factor, saturation curve when delivering full-load current to a

condensive load, (*b*) the synchronous-impedance method, plot the zero-power-factor saturation curve when delivering full-load current to a condensive load, (*c*) the m.m.f. method, plot the zero-power-factor saturation curve when delivering full-load current to a condensive load. (*d*) What is the core loss at rated potential when each curve is taken? (*e*) What is the change in phase position of the field poles from zero power factor lagging to zero power factor leading?

28. Several similar turbine-driven alternators are operating in parallel, delivering equal loads at the same power factor to an inductive load. The steam is cut off from one turbine, but no other adjustment is made. What will be the effect on (*a*) the current and power factor of this particular alternator, (*b*) the current and power factor of each of the others, (*c*) the terminal potential?

29. The speed-load characteristics of two identical turbines are straight lines which show a drop in speed of 4 per cent from no load to full load. These turbines drive two identical 3-phase, Y-connected, 60-cycle alternators which are operating in parallel at rated frequency and potential. Each alternator is carrying three-quarters of its rated load. The excitations of the alternators are equal. (*a*) If the circuit breakers in the armature of alternator 1 open, what will be the terminal potential of this alternator after steady conditions have been reached? (*b*) How will the current and power factor of the load on the station change when alternator 1 goes off the circuit, when the load consists of (1) incandescent lamps operated through static transformers, (2) synchronous motors which were operating at unity power factor before the circuit breakers opened?

Neglect the effect of the change in frequency in question (*b*). In answering question (*a*), use the general method, for calculating the regulation of an alternator, and obtain the values of armature reaction and armature leakage reactance from the Potier triangle.

The following table gives the necessary data for the alternators. Rating, 12,000 kv.-a., 60 cycles, 6600 volts; ohmic resistance per phase, 0.018 ohm; ratio of armature effective resistance to armature ohmic resistance, 2.1.

Field current	Open-circuit potential	Terminal potential, zero power factor with 1050 amperes per terminal
100	3,650	.....
175	5,900	0
200	6,400	1,000
250	7,170	2,800
300	7,700	4,420
350	8,050	5,520
400	8,270	6,300
450	8,400	6,820

30. Two similar alternators are driven by identical steam turbines. These alternators are initially operating in parallel with equal excitations and equal inductive loads. The constants of the alternators are identical. What will take place under the following conditions? (*a*) The steam is cut off from one of the turbines, but no other change is made. (*b*) The circuit breakers of one alternator are open.

In both parts, answer the following questions: What change takes place in (1) the current, load, and power factor of each alternator, (2) the terminal potential of each alternator, (3) the frequency of each alternator?

31. Two alternators A and B, which have the same frequency and potential rating, operate in parallel and carry a combined inductive load of 1500 kw., at 0.8 power factor. The governors of the prime movers and the excitations of the alternators are so adjusted that the potential and frequency of the system are 2300 volts and 60 cycles, respectively, and that the alternators divide the load in proportion to their ratings and operate at the same power factor. The following table gives the ratings and constants of the alternators:

	Alternator A	Alternator B
Kilovolt-ampere rating	1,000	1,500
Rated potential	2,300	2,300
Rated frequency	60	60
Connection	Y	Δ
Phase r_e	0.065 ohm	0.13 ohm
Phase x_s	1.40 ohm	3.30 ohm

The kw. load carried by alternator A is now reduced to zero by changing the governors of the prime movers in such a way that the frequency of the system is unaltered. The excitation of alternator A is not changed, but that of alternator B is adjusted to maintain rated terminal potential. When these adjustments have been made, what current will (*a*) alternator A carry, (*b*) alternator B carry? (*c*) What will be the excitation e.m.f. of alternator B?

32. Two identical, 1500 kv.-a., Y-connected, 5500-volt, 50-cycle, 3-phase alternators 1 and 2 operate in parallel and supply a load which takes 150 amp. at 5500 volts and unity power factor. The excitations of the alternators are equal, and each alternator supplies one-half of the load.

The power load carried by alternator 1 is now reduced to zero by adjusting the governors of the prime movers. The frequency is maintained constant at 50 cycles. The excitation of alternator 2 is then adjusted until the terminal potential of the system is brought back to 5500 volts. The excitation 1 is not changed. (*a*) If the terminal potential of the system is taken as the axis of reference, what is the complex expression for the current carried by alternator 1 after the adjustments have been made? (*b*) What is the complex expression for the current carried by alternator 2? The effective resistance and the synchronous reactance of each alternator are 0.36 and 6.5 ohm, respectively. (*c*) Draw the vector diagrams for the two conditions.

33. The ratings and other data relating to two dissimilar 3-phase, 60-cycle, 6600-volt alternators A and B are given below.

	A	B
Kilovolt-ampere rating..........	5,000	1,000
Connections......................	Y	Δ
Ohmic resistance between terminals..	0.084	0.10
Ratio of effective to ohmic resistance.	1.65	1.50

ALTERNATOR A

Field current	Open-circuit terminal potential	Terminal potential, zero power factor, 440 amperes per terminal
64	3,050	0
100	4,800	1,800
150	6,500	4,200
200	7,400	5,700
250	7,900	6,600
275	8,150	6,900

ALTERNATOR B

Field current	Open-circuit terminal potential	Terminal potential, zero power factor, 84 amp. per terminal
50	4,400	....
80	6,500	....
110	7,800	5,375
140	8,625	6,600
180	9,445	7,800

These machines are operated in parallel and carry a combined load of 5500 kv.-a. at 0.90 power factor, 6600 volts, and 60 cycles. (*a*) If the kilowatt load is divided between the alternators in proportion to their ratings and alternator A operates at 0.95 power factor, what are their excitations? (*b*) If the kilovolt-ampere load on alternator B is now reduced to zero without changing either the terminal potential or the frequency of the system, what must be the excitation of each alternator? Through what phase angle in electrical degrees must each alternator swing to produce this condition?

34. Two identical Y-connected, 60-cycle, 3-phase alternators each have a synchronous impedance of $z_s = 0.1 + j2.0$ ohms. These alternators, operating in parallel, supply an inductive load of 1200 kw. at 0.8 power factor and 60 cycles with 2400 volts between line terminals. Alternator 1 carries 900 kw. (*a*) If the field excitations are so adjusted that the currents delivered by the alternators are in phase, what will be the magnitudes of the excitation e.m.fs.? (*b*) The kilovolt-ampere load on alternator 2 is now reduced to zero in such a way that the potential

and frequency of the system are still 2400 volts and 60 cycles. If, now, the circuit breakers of alternator 2 are opened, what will be the terminal potential of each machine after steady conditions have been attained?

35. What is *hunting* of a synchronous machine? Why are synchronous machines much more subject to hunting than assynchronous machines? How can it be diminished? What is meant by *stiffness of coupling* of a synchronous motor? How is this affected by increasing the air gap? What adjustment takes place in a synchronous motor to meet the demand of an increase in load? If a synchronous motor is to be used only as a synchronous condenser to correct the power factor of a distribution system, should the ratio of armature ampere-turns to field ampere-turns be large or small? Should the air gap be relatively long or short?

36. A 60-hp., 440-volt, 3-phase, Δ-wound synchronous motor has a resistance of 0.2 ohm and a synchronous reactance of 4.0 ohms per phase. Its saturation curve is a straight line to $E = 360$ volts, for which point the field current is 11 amp. For 400, 440, and 520 volts, the field currents are 12.5, 14, and 19, respectively. Find the power factor at an output of 20 hp. and with a field current of (*a*) 10 amp. (*b*) 12 amp. (*c*) Find the breakdown point with a field current of 12 amp. (*d*) Find the field current for unity power factor at an output of 100 hp. Assume that the rotation losses are 3.5 hp.

37. The following data relate to a certain 1340 hp., 13,200-volt, 3-phase, Y-connected synchronous motor:

Field current	Open-circuit terminal potential	Terminal potential, $I = 42$ amperes, power factor $= 0$	Core loss, kilowatts on open circuit
50	8,800	......	7.5
80	13,000	......	16.6
110	15,600	......	25.4
140	17,250	13,250	35.5
180	18,900		

Effective resistance per phase, 2.18 ohms; field resistance, 0.541 ohm; friction and windage loss, 11 hp.

The field excitation is from an exciter mounted on the shaft of the motor. The efficiency of the exciter may be assumed to be 86 per cent.

The motor is to be operated to correct the power factor of a 13,250-volt line and, at the same time, to supply additional power. The load on the system before adding the synchronous motor is 1000 kw. at 0.7 power factor with lagging current. If the motor current is limited to 45 amp. and the power factor of the system is to be raised to unity, how much power can the motor supply?

38. In a factory, there is, at present, an induction motor load taking 1000 kw. at 0.71 power factor. It is desired to add other motors, operating at the same power factor, and, at the same time, a synchronous condenser (motor), so adjusted that the new kilovolt-ampere load will just equal the original kilovolt-ampere load, and the resulting power factor will be 0.90. Assume that the full-load losses of the synchronous condenser are 8 per cent of its rated capacity. Also, assume that the full-load synchronous-impedance drop is 35 per cent of the rated potential. What is (*a*) the added induction motor load in kilowatts, (*b*) the kilovolt-ampere capacity of the smallest synchronous condenser that will accomplish this? (*c*) To what per cent of its rated potential should it be possible to increase the excitation e.m.f. of the synchronous condenser?

39. A 6-phase synchronous converter has 21 slots per pole. The pitch of the armature coils is unity. An analysis of the potential between diametrical slip rings shows it to contain a fundamental of 100 per cent, a third harmonic of 12 per cent, and a fifth harmonic of 8 per cent. From this data, predict the analysis of the potential between adjacent slip rings. If a voltmeter connected across diametrical slip rings reads 460 volts, what will it read when connected across adjacent slip rings?

40. An 8-pole, 6-phase, 1000-kw., 25-cycle, 600-volt (direct-current) synchronous converter has 168 armature slots with 6 inductors in each. The armature winding has full pitch. The curve of the air-gap flux is

$$B = B_1 \sin x + 0.3B_1 \sin 3x + 0.2B_1 \sin 5x$$

where x is measured from a point midway between any pair of adjacent poles.

What is the ratio of the alternating-current potential between (*a*) adjacent armature taps to the potential between direct-current brushes, (*b*) between alternate armature taps to the direct-current potential between brushes?

41. What effect will hunting have on the operation of a synchronous converter? Why is the heating in the armature of a converter not uniform? Under what conditions is the ratio of the alternating-current to the direct-current potential of a converter given by the formula

$$\frac{1}{\sqrt{2}} \sin \frac{\pi}{n}$$

How can this ratio be altered?

A 6-phase 3000-kw. converter receives power from a 3-phase 2300-volt transmission line through transformers with primaries in Y and secondaries in double Δ. The direct-current potential of the converter is 600. What must be the current and potential rating of all coils of the transformers? Neglect the losses in both the transformers and in the converter.

What is gained by the use of a 6-phase instead of a 3-phase converter?

42. A compound synchronous converter is operating from a constant-potential alternating-current source and is delivering its rated kilowatts on the direct-current side. The series field winding has 2 turns per pole. The shunt-field current is maintained constant and is adjusted so that the power factor is unity. If the series field is shunted so that the current in it is reduced to two-thirds of its former value, the power factor becomes 95 per cent. What would be the power factor if 1 more turn per pole were added to the series winding (without shunt)?

43. A 1200-volt (direct-current), 1000-kw., 6-phase, compound, 60-cycle synchronous converter is operating at rated potential, frequency, and unity power factor with an output of 800 kw. If the load increases to 1200 kw., how much must the shunt-field current be changed to maintain unity power factor? Must it be increased or decreased? Assume that the potential and frequency impressed on the alternating-current side remain unchanged, and neglect any change in the direct-current potential caused by the resistance drop in the armature.

The following table gives the necessary data for the converter:

Number of poles............	12	Armature resistance between direct-current brushes...........	0.0236 ohm
Number of armature slots.. ..	180	Shunt-field resistance..	147 ohms
Number of series armature inductors per slot...........	12	Series-field resistance..	0.0025 ohm
Number of shunt turns per pole	1,628	Friction and windage loss...............	9.1 kw.
Number of series turns per pole	4		

44. A 100-kw., 220-volt, 3-phase synchronous converter receives power from a 1100-volt, 2-phase circuit. Show how the transformers are connected, and specify their current and potential ratings.

45. A Y-connected, 3-phase, 4-pole induction motor has 6 slots per pole, with 20 inductors per slot. Each phase of the motor is series connected and has a five-sixth pitch. The mean radius of the air gap is 20 cm., and the length of the armature iron parallel to the shaft is 15 cm. The air gap is 1 mm. The effective value of the magnetizing current per phase is 14.14 amp. (*a*) Plot the curve of flux density in the air gap for the instant when the current in phase 1 is a maximum. Neglect the reluctance of the iron and the effect of the slots. (*b*) What is the flux per pole at the instant when the current in phase 1 is a maximum? Use a scale of 2000 gausses to an inch. Place slots 0.5 in. apart.

46. The stator of a 12-pole wound-rotor induction motor is connected to a 60-cycle line. The slip rings of the rotor are connected to a 25-cycle line; what will be the resultant speed of the motor?

47. What would be the effect of placing a rotor wound for 10 poles in a stator wound for 12 poles on a 60-cycle circuit? What would happen with a rotor of 6 poles?

48. The air gap of an induction motor is increased by turning down the rotor. What will be the effect on the (*a*) no-load current with rated applied potential, (*b*) no-load core loss with rated applied potential, (*c*) blocked current with the same applied potential, (*d*) breakdown torque with rated applied potential?

49. An induction motor is designed to operate on a 230-volt, 50-cycle circuit. Will the following quantities be increased or diminished if this motor is operated from a 230-volt, 60-cycle circuit: (*a*) no-load current, (*b*) no-load speed, (*c*) no-load core loss, (*d*) breakdown torque, (*e*) starting torque? Give reasons for your answers.

50. What is the effect on the breakdown torque of an induction motor of a drop in the applied potential of 5 per cent? What is the effect on the breakdown torque of a drop in frequency of 5 per cent?

51. During a blocked test on a 3-phase, 36-pole, 25-cycle induction motor, the potential, current, and power are 2200

volts, 369 amp., and 375 kw. The effective stator resistance is 0.65 ohm between terminals. What is the brake torque during the block test?

52. If the temperature of the rotor winding is 25°C. the slip of an induction motor is 1.80 per cent when it is delivering its rated output, what is the approximate value of the slip when the motor is delivering full load after it has been in operation long enough for its temperature to rise to 70°C.? If the starting torque is improved by adding resistance to the rotor circuit, how many times should the rotor resistance of this motor be increased in order that the motor will deliver full-load torque with full-load current at starting?

53. The following incomplete data are given regarding a 3-phase, 60-cycle, slip-ring induction motor: 50-hp.; 440-volts; 8-poles; ratio of transformation 440:220 volts; measured rotor resistance between terminals, 0.068 ohm. Estimate as closely as you can (*a*) the slip at full load, (*b*) the full-load torque, (*c*) the amount of resistance that must be connected in series with each phase in order that, when starting, the motor will develop full-load torque when taking full-load current at rated potential.

54. An induction motor has a certain breakdown torque. What would be the effect on this torque of (*a*) doubling the stator resistance, (*b*) doubling the stator reactance, (*c*) increasing the impressed potential, (*d*) lenghtening the air gap. Prove your statements.

55. A polyphase induction motor with a wound rotor breaks down at 200 per cent full-load torque, at a slip of 16 per cent. What would be the effect on the maximum torque and slip at maximum torque of (*a*) increasing the rotor resistance, (*b*) doubling the number of rotor turns and halving the cross-section of the wire used in the rotor winding, (*c*) reducing the impressed potential, (*d*) increasing the reactance of (1) the rotor, (2) the stator, (*e*) reducing the frequency? Is it feasible to control the speed of an induction motor by varying the potential impressed upon its stator? How may the speed be varied?

56. The relation between the speed and torque of an induction motor is varied by means of a controller which inserts more or less resistance in the rotor circuit. With the rotor slip rings short circuited, the slip is 0.025 when full load is delivered. If the controller is adjusted so that 0.26 ohm is inserted in each phase, the motor still delivers full-load torque but at a slip of 0.5. How

much resistance should be inserted in each phase so that the motor will develop full-load torque at starting? The applied potential is constant.

57. At standstill, with 2200 volts impressed on the stator terminals of a 3-phase induction motor, the potential across the open rotor slip rings is 610. With the rotor blocked and the slip rings short circuited, the line potential, line current, and power supplied to the stator are 750 volts, 288 amp., and 116 kw. With the rotor blocked what resistances should be connected in star to the rotor slip rings so that the line current will be 288 amp. when 2200 volts is impressed on the stator? What is the ratio of the torques developed in the two cases? Neglect the exciting current.

58. At full load, the slip of a 1000-hp., 2200-volt, 25-cycle, 3-phase induction motor is 0.019. The resistance of the stator and rotor windings, referred to the stator, are, respectively, 0.083 and 0.105 ohm per phase at 25 cycles. The equivalent leakage reactance as measured with the rotor blocked is 0.64 ohm per phase. The motor is wound for 12 poles, the windings are connected in Y, and the ratio of transformation is 2200:1500. (*a*) What resistances should be connected across the rotor slip rings in order that the motor will develop full-load torque when starting on full potential? (*b*) What is the ratio of pull-out torque (maximum torque) to full-load torque? Slip rings short circuited. (*c*) What change would be produced in the starting torque and pull-out torque by a reduction of frequency to 24 cycles? (*d*) What would be the change in the core loss by this change in frequency?

59. The constants per phase of a 1000 hp., 3-phase, Y-connected 2200-volt, 25-cycle, 12-pole induction motor are

$$r_1 = 0.065 \text{ ohm (ohmic)}$$
$$r_2 = 0.0386 \text{ ohm (ohmic)}$$
$$x_1 = 0.32 \text{ ohm at 25 cycles}$$
$$x_2 = 0.1487 \text{ ohm at 25 cycles}$$

The ratio of effective to ohmic resistance is 1.27 for both rotor and stator. The ratio of transformation of stator to rotor is 1.5.

When operated at no load, with rated potential and frequency impressed on the stator, the current per terminal and total power are 75.1 amp. and 15.2 kw. The friction and windage loss at rated potential and frequency is 3.1 kw. (*a*) What is

the ratio of breakdown torque to full-load torque at rated potential and frequency? (b) How much resistance must be inserted in the rotor circuit between slip rings to give maximum torque when starting with rated potential and frequency impressed on the stator?

60. It is to be decided whether to start an induction motor by means of a compensator, which reduces the potential applied to the stator terminals, or by inserting balanced resistances in the rotor circuit. In each case, the current drawn from the supply circuit must be the full-load current taken by the motor under normal operating conditions, *i.e.*, with full potential applied and the slip rings short circuited. With 20 per cent of rated potential, the motor takes full-load current at 25 per cent power factor, when the rotor is blocked and short circuited. Assume that the stator and rotor resistances at this time are equal. Compare the starting torques for the two methods of starting.

61. A 3-phase, Y-connected, 2200-volt, 60-cycle, 44-pole induction motor at the instant of starting develops an internal torque of 792 lb.-ft. when the impressed potential and frequency are, respectively, 500 volts and 60 cycles. Under these conditions, the current is 152 amp., and the power consumed is 40.1 kw. At no load, the motor takes 13.5 kw. and 39.8 amp. per terminal when rated potential and frequency are impressed. What is (a) the rotor effective resistance per phase referred to the stator, (b) the stator effective resistance per phase, (c) the breakdown torque of the motor at rated frequency and potential? At starting, the exciting current may be neglected. This current must not be neglected under running conditions. Assume that the rotor and stator reactances at rated frequency are in the same ratio as the rotor and stator effective resistances.

62. An 8-pole, 60-cycle, 3-phase, Y-connected (both rotor and stator) 2200-volt induction motor breaks down, when operated at rated potential and frequency, at 200 per cent of full-load torque and at a slip of 16 per cent. The rotor ohmic resistance of this motor is 0.077 ohm per phase, and the ratio of effective resistance to the ohmic resistance at 60 cycles is 1.8. (a) What is the minimum speed at which the motor can be operated, when developing full-load torque, by reducing the impressed potential? If the drop in the stator winding due to the exciting current is neglected, how much would the impressed potential have to be reduced?

(*b*) How much resistance must be added between each pair of rotor slip rings in order that the motor shall develop 200 per cent full-load torque at starting with rated potential and frequency impressed on the stator?

(*c*) If the number of turns in the rotor windings is doubled and the cross-section of the wire is halved, what will be the breakdown torque of the motor in per cent of its breakdown torque before the number of turns were changed? At what slip will this torque occur? The motor is assumed to operate at rated frequency and potential.

(*d*) If the number of turns in the stator windings is now doubled and the cross-section of the wire is halved, what will be the rating of the motor when operated at 4400 volts and 60 cycles? How will the full-load power factor, efficiency, torque, and slip at the new rating compare with the full-load power factor, efficiency, torque, and slip of the motor before its windings were changed?